Figure 1: Categories of Defects in Sewer Pipes

Figure 2: Root Intrusion
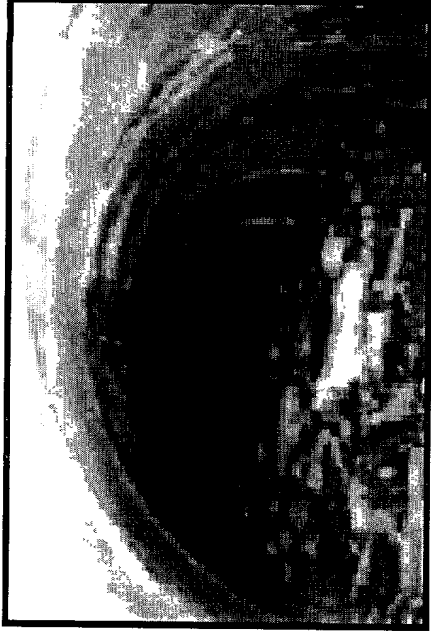

Figure 3: Dirt Deposits

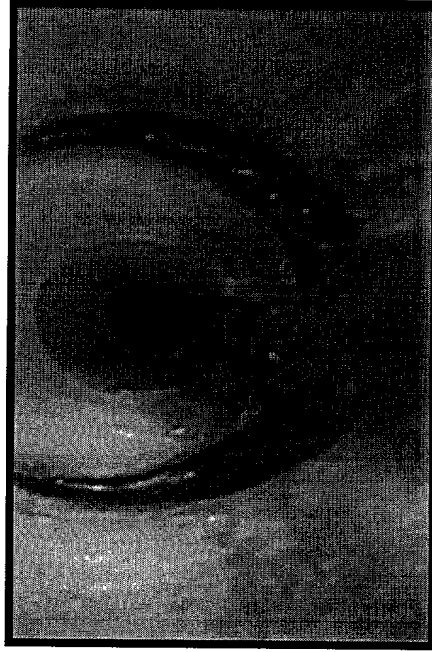Figure 4: Infiltration

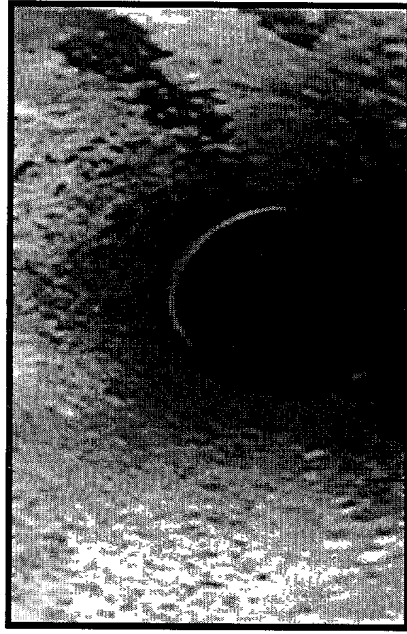Figure 5: Cracks

Figure 6: Misalignments
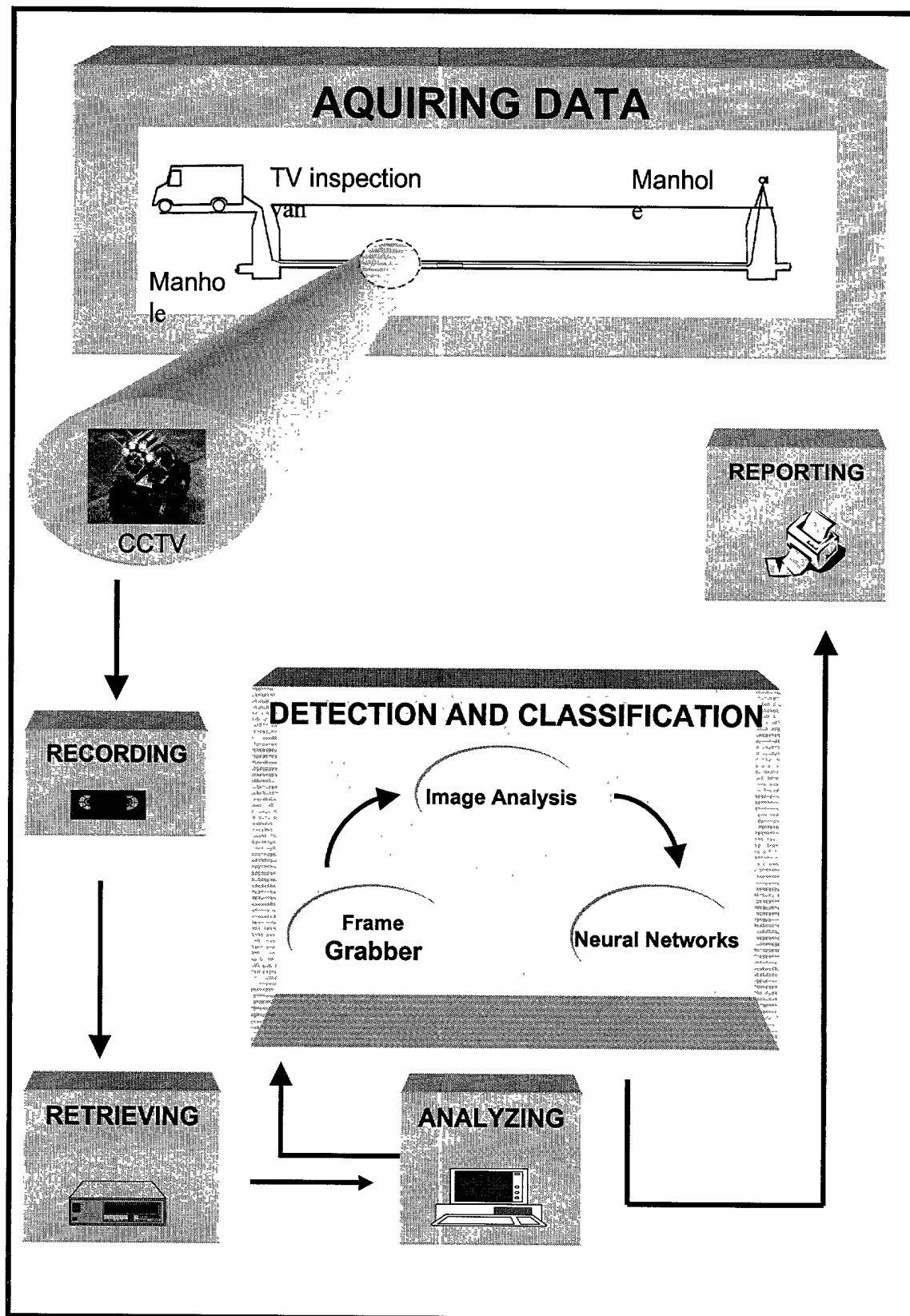
Figure 7: Proposed Automated Detection and Classification System

AQUIRING DATA

TV inspection van

Manhole

Manhole

CCTV

REPORTING

RECORDING

DETECTION AND CLASSIFICATION

Image Analysis

Frame Grabber

Neural Networks
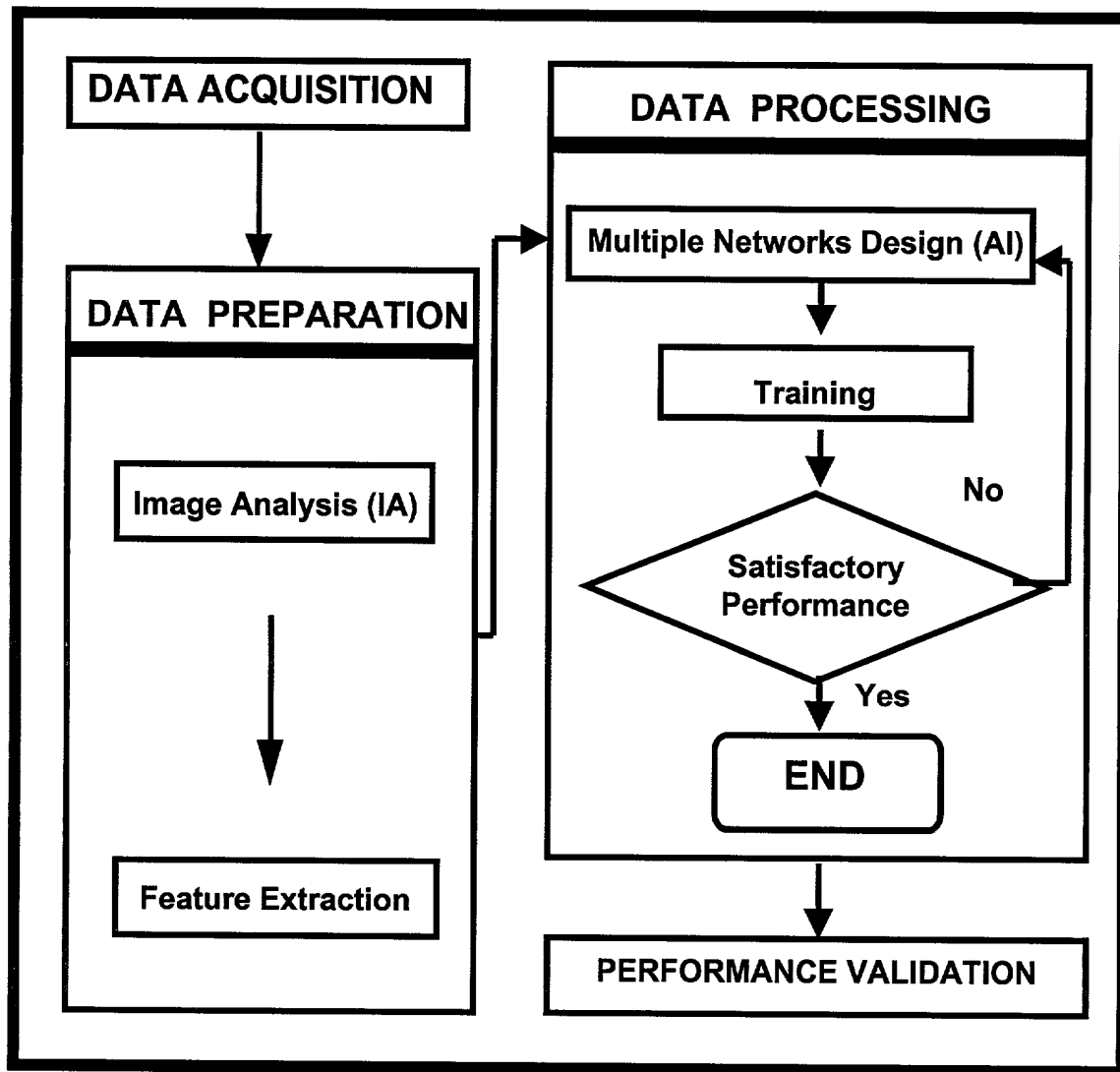
RETRIEVING

ANALYZING

Figure 8: Methodology for Developing Automated Detection System
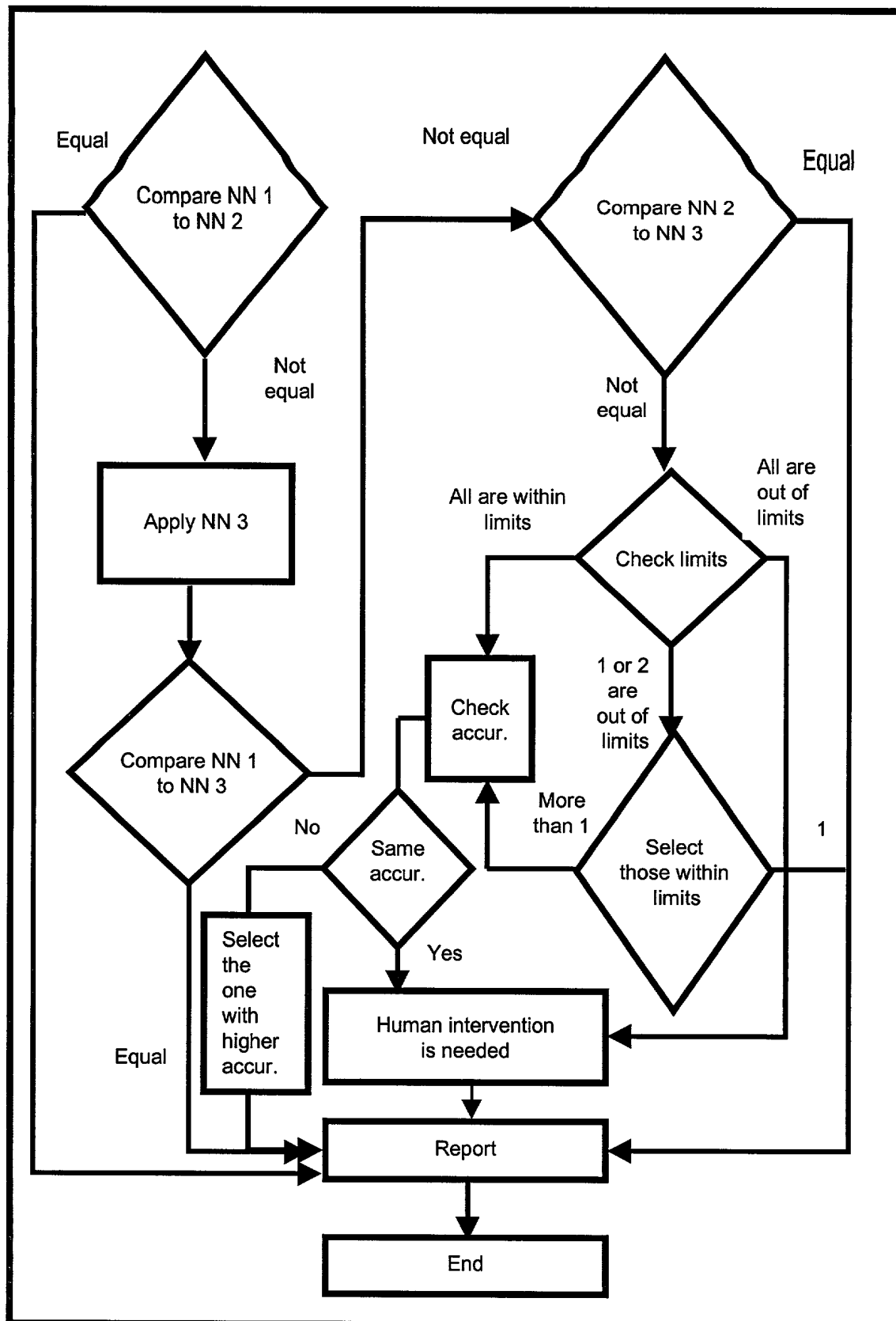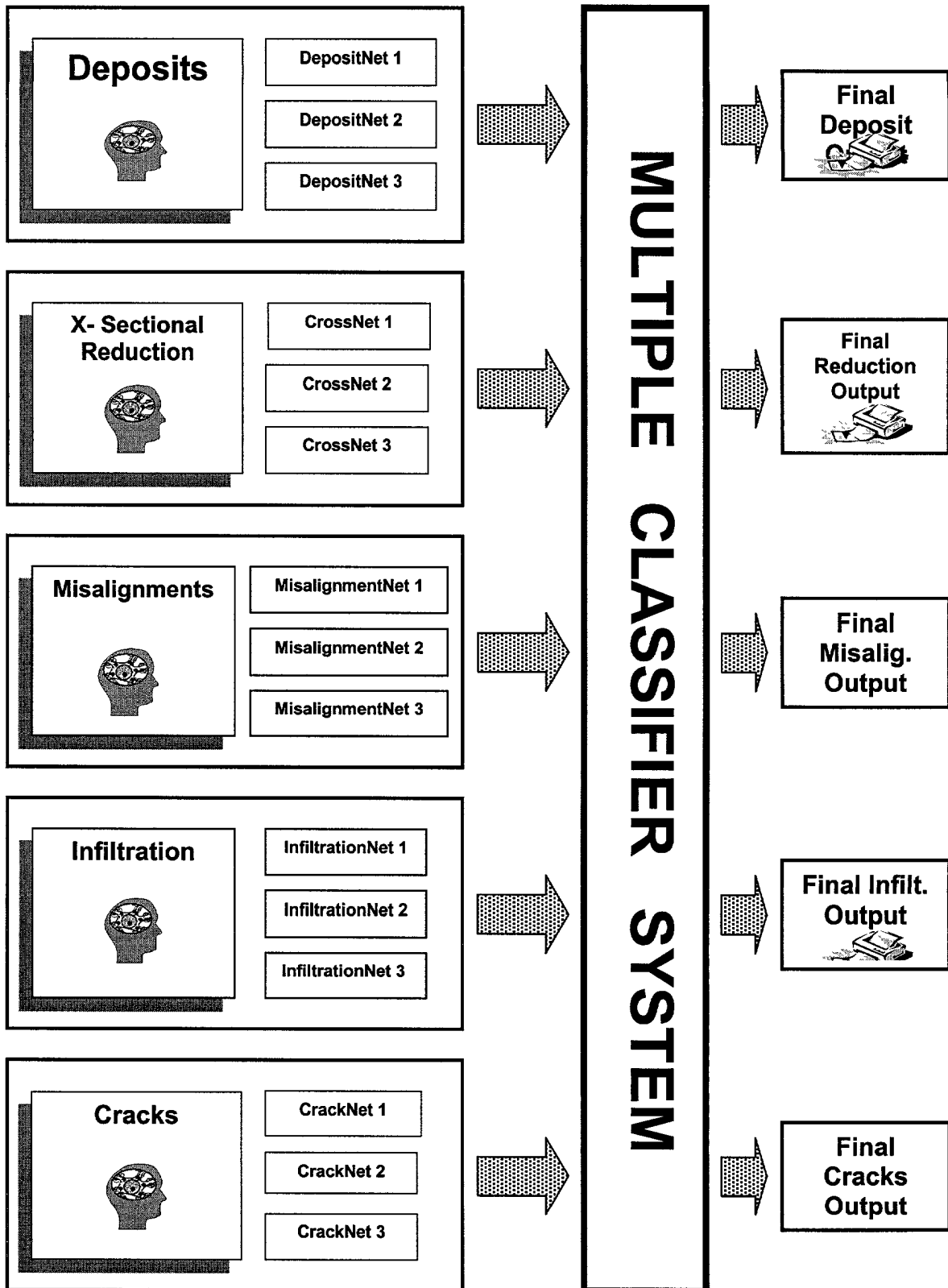
Figure 9: Algorithm of the Multiple Classifier System

Figure 3-10: Utilization of the Multiple Classifier System

INPUT VIDEOTAPE

Inverted Images

Non-Inverted Images

SET # 1

Deposits

Classified Deposits

All non-deposits with (1,1) coordinates

Non- edge detection

Edge detection

SET # 2

Cross- Sectional Reduction

SET # 3

Misalignments

SET # 4

Infiltration

SET # 5

Cracks

Classified cross-sectional reduction

All non-X-sectional reductions (ignore)

Classified misalignments

All non-misalignments (ignore)

Classified Infiltration

All non-defects (ignore)

Classified Cracks

All non-cracks (ignore)

Figure 3-11: Solution Strategy
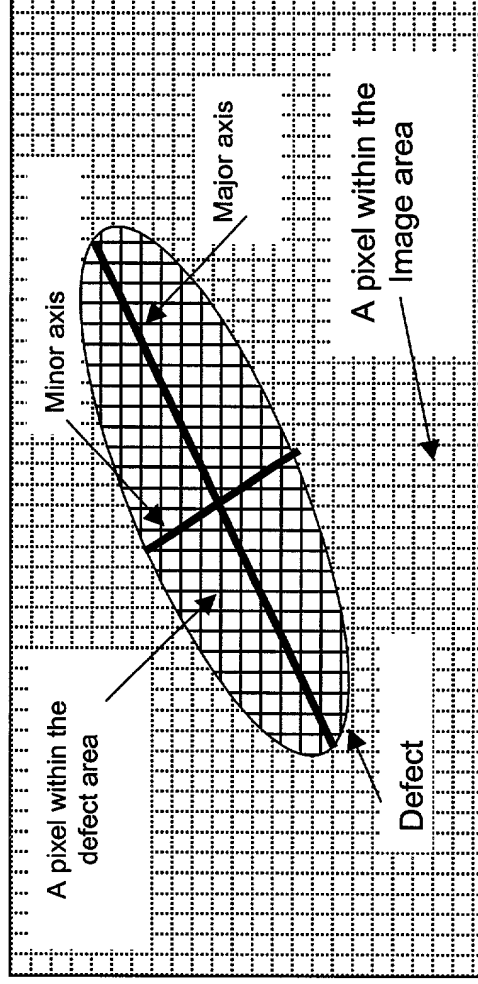
Figure 12: Geometrical Attributes of Defects

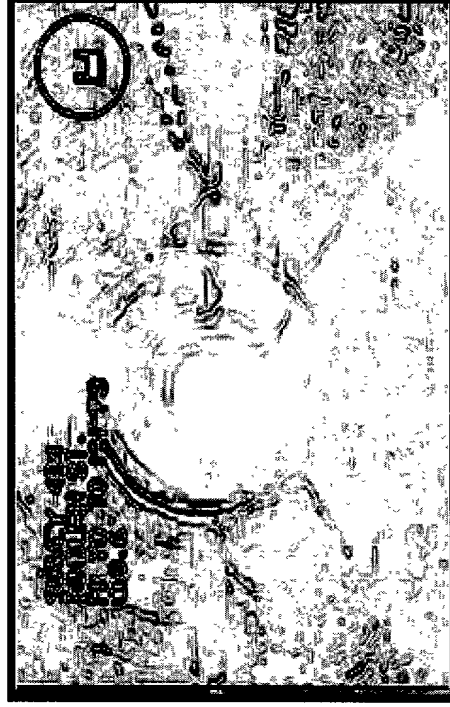Figure 15: Dilated Image of Cracks

Figure 16: Thresholded Image of Cracks
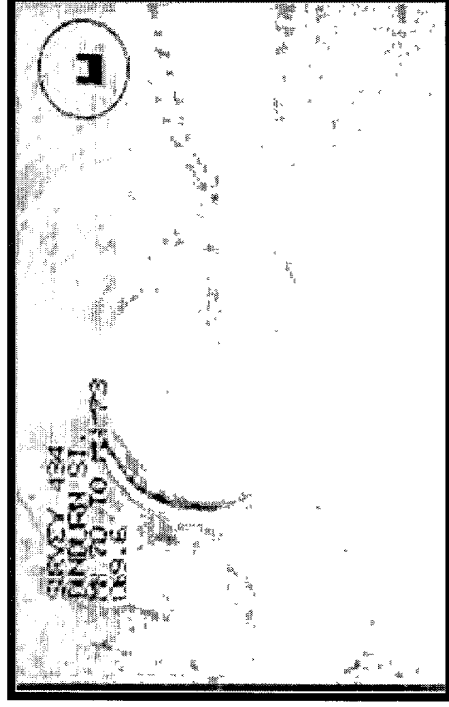
Figure 13: Background Subtracted Image of Cracks

Figure 14: Edge Detected Image of Cracks

Figure 17: Segmented Image of Cracks

: Results

	Area	Mean	S.D.	X	Y	Length	Major
1.	10298.00	190.81	66.39	53.65	71.71	1524.50	158.94
2.	243.00	128.24	43.82	219.07	7.41	104.81	28.39
3.	136.00	111.10	21.24	244.56	4.30	65.70	17.86
4.	2159.00	188.20	70.57	282.51	35.62	368.13	61.65
5.	292.00	131.72	32.81	202.45	17.68	89.01	31.38
6.	192.00	109.64	23.06	202.17	51.82	118.71	24.13
7.	241.00	130.94	42.37	178.54	59.96	101.64	23.34
8.	1345.00	168.22	65.38	259.09	87.75	399.50	95.43
9.	185.00	140.76	49.97	205.39	84.36	68.87	17.46
10.	356.00	143.16	44.28	176.45	103.95	96.43	29.89
11.	177.00	137.53	39.02	201.72	105.62	56.63	18.03
12.	591.00	142.98	50.42	37.24	123.74	175.10	51.35
13.	4009.00	145.72	47.18	281.45	174.64	761.11	88.82
14.	251.00	136.23	42.46	186.72	144.71	90.08	30.47
15.	136.00	119.99	31.48	88.65	158.98	59.84	22.41

Figure 18: Analysis Results of an Image Depicting Cracks

Figure 19: Contribution Values of Attributes Utilized in Designing the Preliminary Neural Network for Classification of Cracks

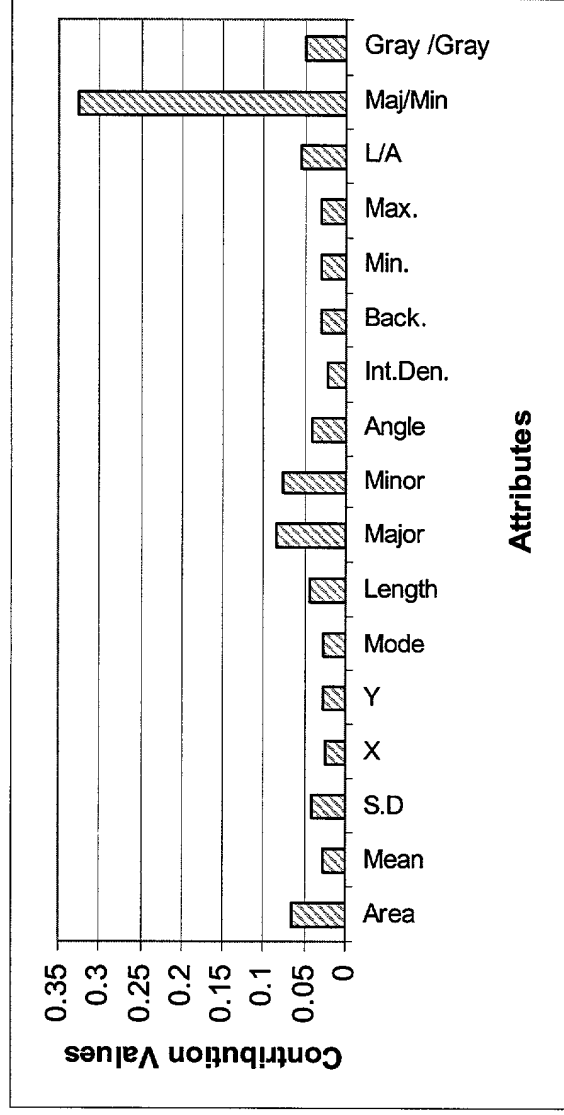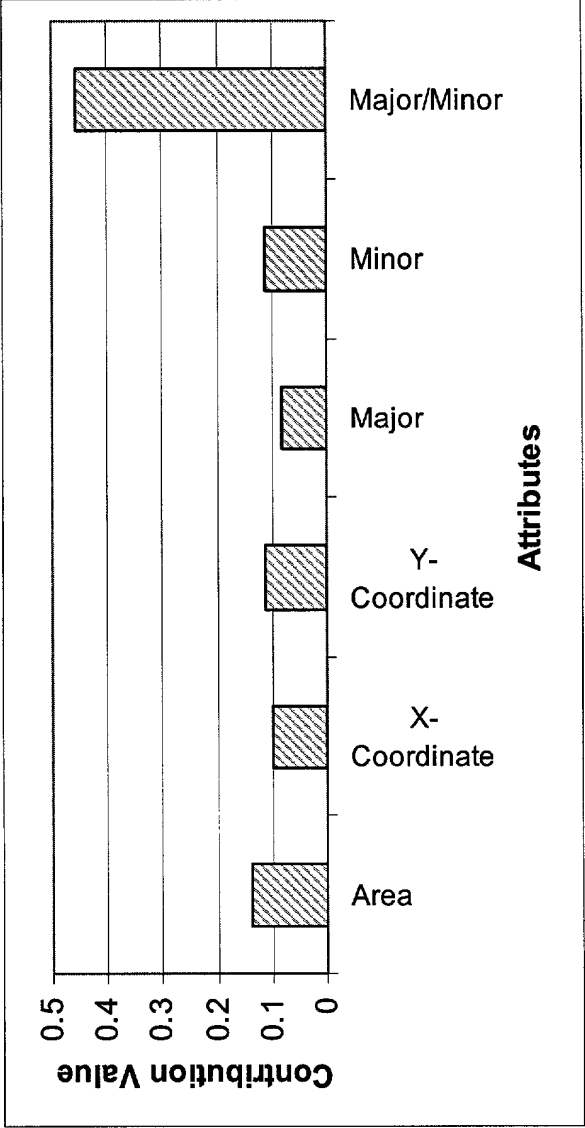**Figure 20: Contribution Values of Attributes Utilized in Designing Neural Network # 1 for Classification of Cracks**
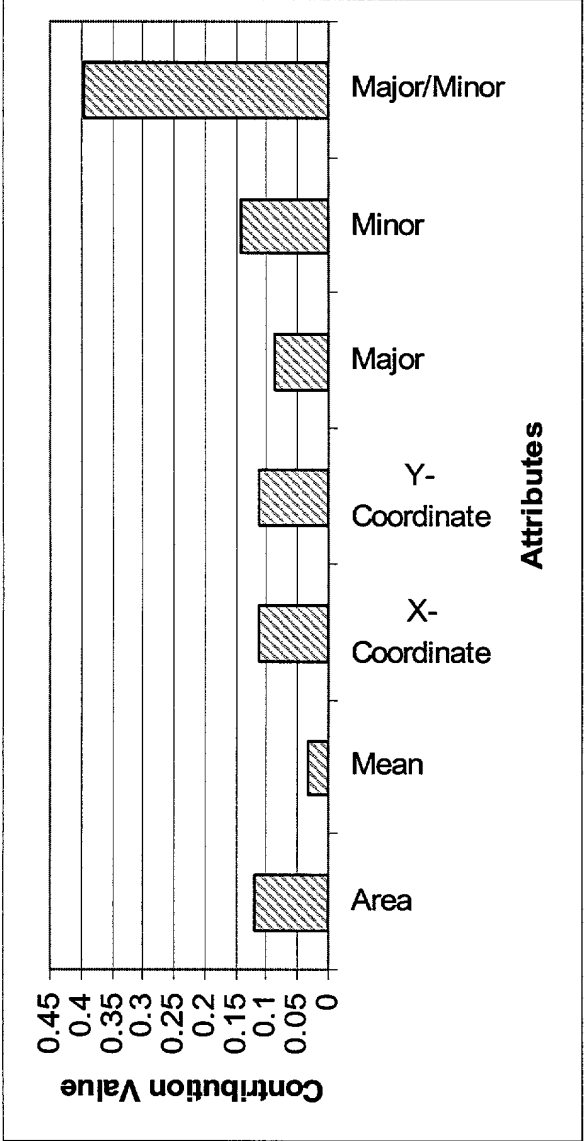
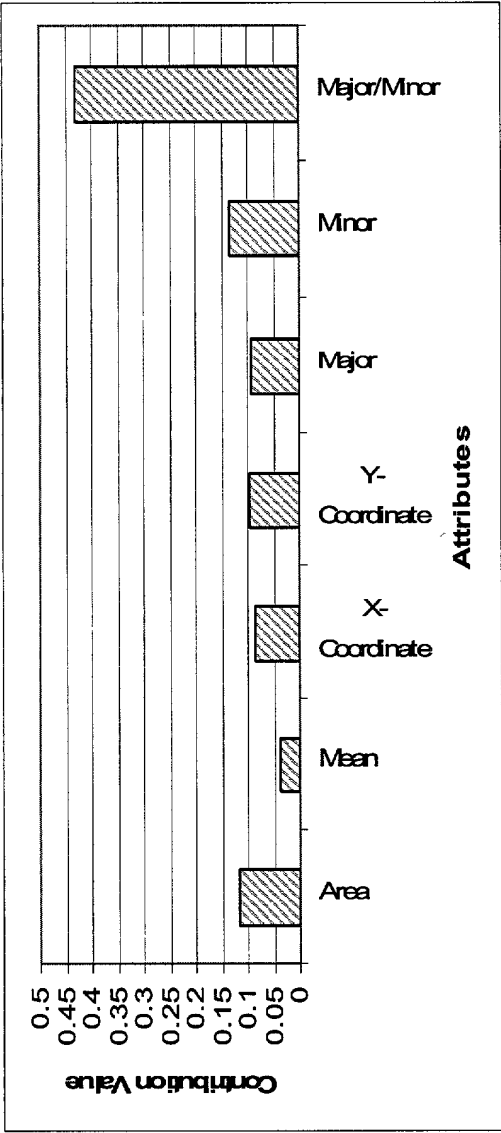**Figure 21: Contribution Values for the Selected Attributes Utilized in Designing CrackNet 2**

Figure 22: Contribution Values for the Selected Attributes Utilized in Designing CrackNet 3

Figure 23: Segmented Image of a Case Example on Cracks

Number of row with variable names (blank if none):

First row containing actual training data: 2

☒ left/right arrow keys end edit

Size: 100 rows 20 columns

Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options menu allows you to change the datagrid call to your own spreadsheet. Search help file for "datagrid" for details.

	D	E	F	G
2	0.035929877311	0.9687371253397		
3	0.114000715315	0.8862966689510		
4	0.000000000000	1.0000000000000		
5	0.000000000000	1.0000000000000		
6	0.100026234984	0.9002998847126		
7	0.031811475754	0.9688777077103		
8	0.000000000000	1.0000000000000		
9	0.893140494823	0.1043598865189		
10	0.019607180730	0.9805549997921		
11	0.0039828819617	0.9895788843117		
12	0.005694665015	0.9951223731104		
13	0.573563754559	0.4288129806652		
14	0.044550366700	0.9630264639985		
15	0.421342730522	0.5780738859215		
16	0.706838846207	0.2927024662249		
17				
18				

Figure 24: Output Results of a Case example on Cracks
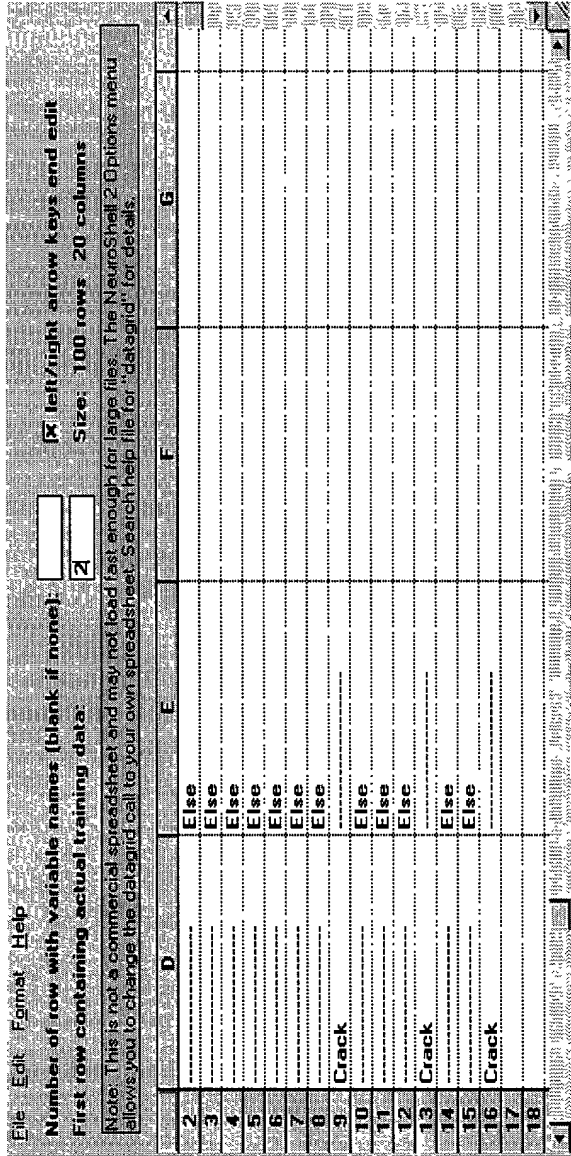
Figure 25: Thresholded Output Results of a Case example on Cracks
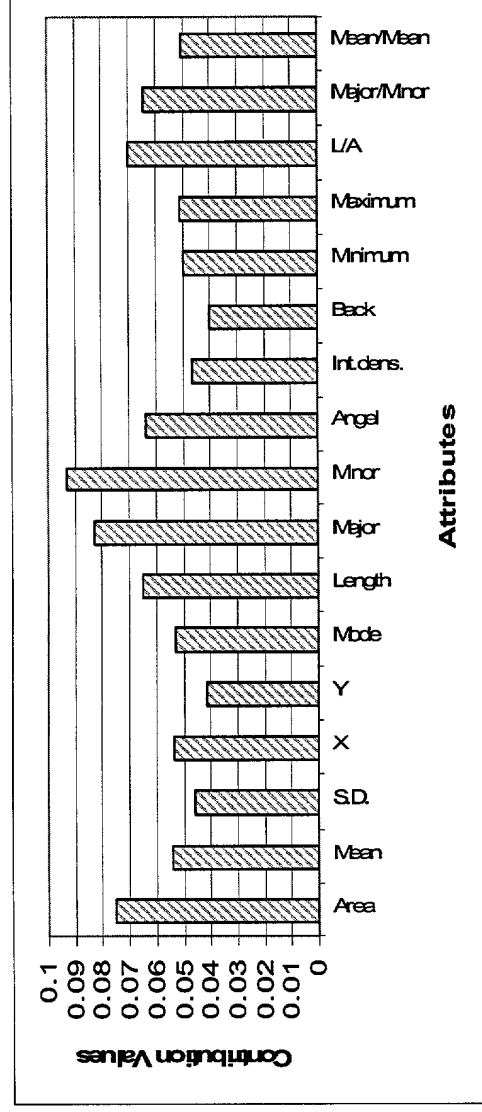
Figure 26: Contribution Values of Attributes Utilized in Designing InfiltrationNet 1

Figure 29: Thresholded Image of Infiltration

Figure 30: Segmented Image of Infiltration
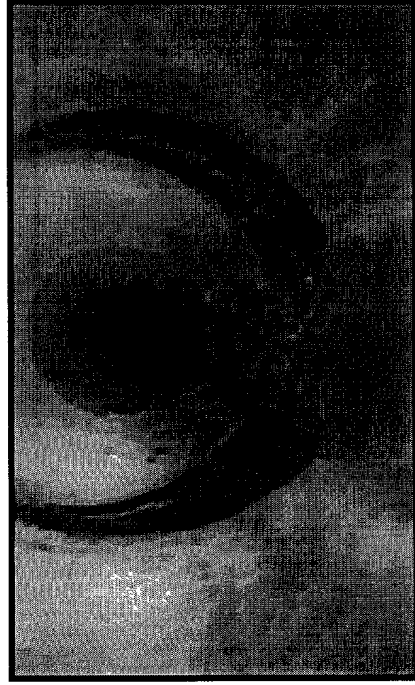
Figure 27: Dilated Image of Infiltration
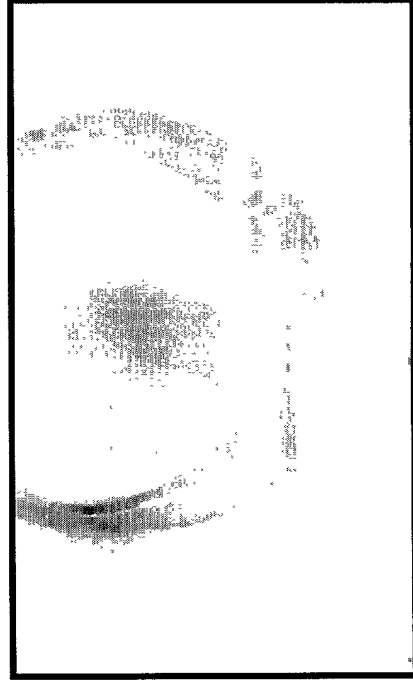
Figure 28: Background subtracted Image of Infiltration

FOSAIF 04200660

Results

	Area	Mean	S.D.	X	Y	Length	Major
1.	2390.00	57.95	26.30	79.89	52.34	371.30	97.58
2.	3032.00	44.43	9.70	240.70	73.93	516.32	118.22
3.	492.00	55.05	34.63	318.00	81.50	332.24	185.05
4.	3609.00	49.03	13.20	159.46	56.57	343.61	87.67
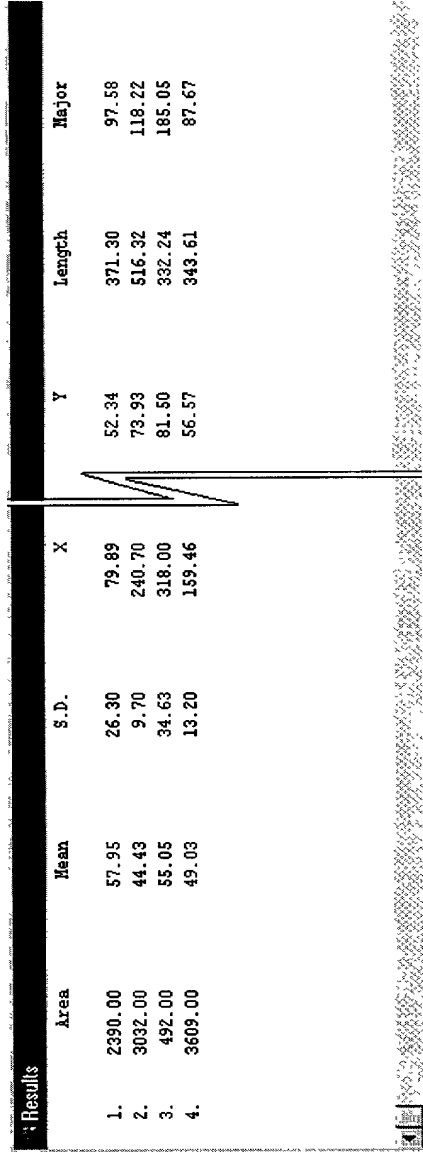
Figure 31: Analysis Results of an Image Depicting Infiltration
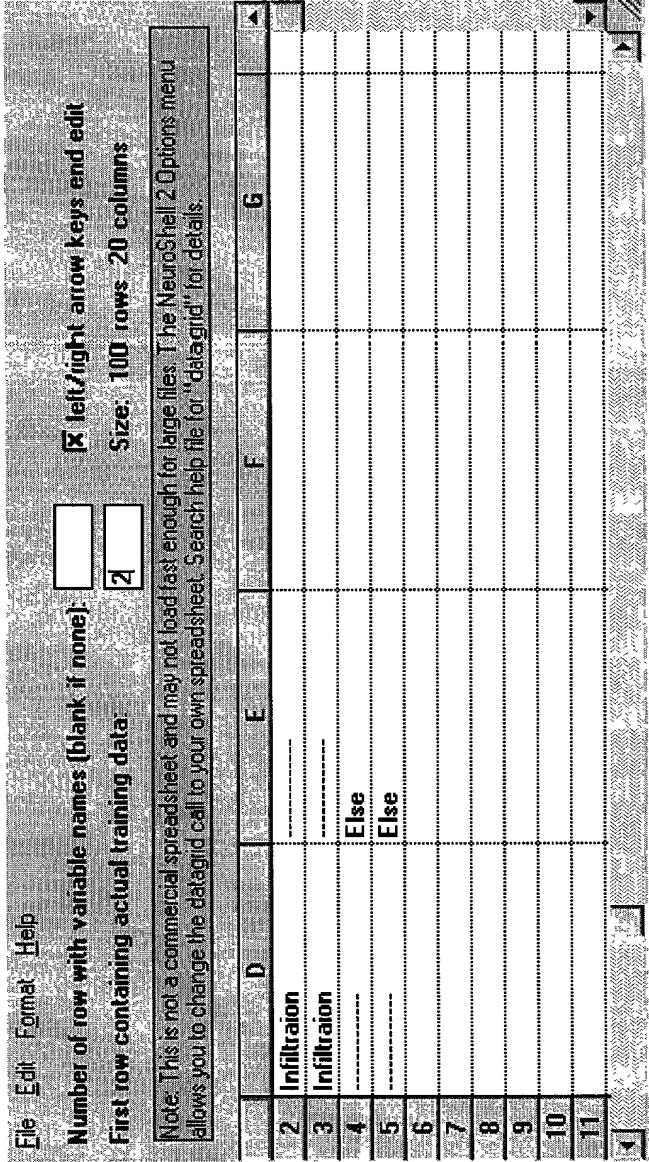
Figure 32: Classification Results of a Case Example on Infiltration
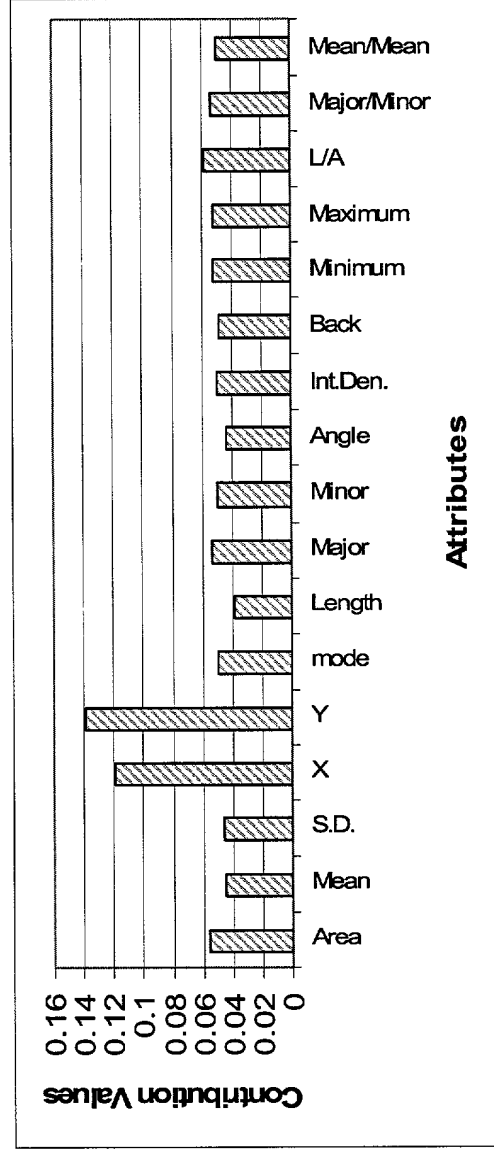
Figure 33: Contribution Values of Attributes Utilized in Designing DepositNet 1

Figure 35: Background Subtracted Image of Deposits

Figure 37: Thresholded Image of Deposits

Figure 34: Inverted Image of Deposits
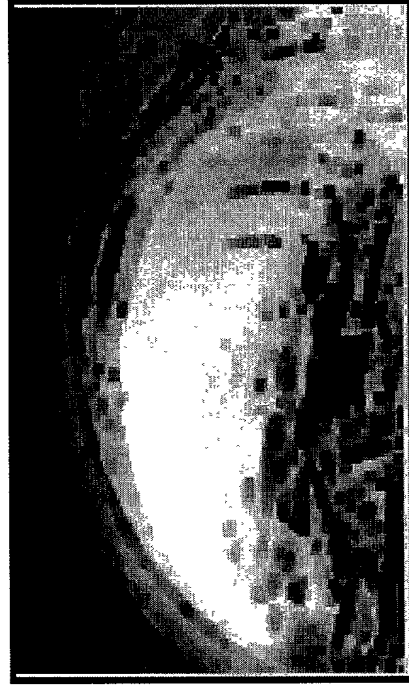
Figure 36: Dilated Image of Deposits

Figure 38: Segmented Image of Deposits

	Area	Mean	S.D.	X	Y	Length	Major
1.	2652.00	80.03	22.30	55.52	37.85	715.94	109.69
2.	108.00	68.61	14.66	161.80	53.11	55.60	17.59
3.	144.00	71.94	16.32	175.35	66.67	70.43	18.30
4.	2972.00	96.81	34.10	69.02	114.82	870.18	98.21

Figure 39: Analysis Results of an Image Depicting Deposits

Number of row with variable names (blank if none):

First row containing actual training data: 2

X left/right arrow keys end edit

Size: 100 rows 20 columns

Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options menu allows you to change the datagrid call to your own spreadsheet. Search help file for "datagrid" for details.

	D	E	F	G
2	Else			
3	Else			
4	Else			
5		Deposits		
6				
7				
8				
9				
10				
11				

Figure 40: Classification Results of a Case Example on Deposits
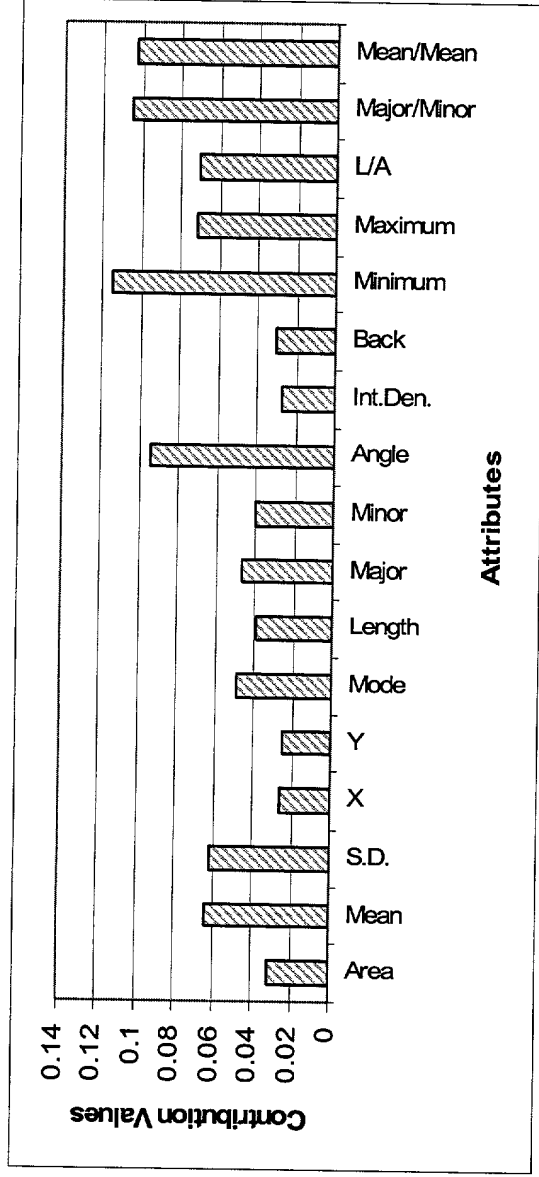
Figure 41: Contribution Values for all Attributes Utilized in Designing a Preliminary Neural Network for Classification of Cross-sectional Reductions

Figure 43: Dilated Image of cross-sectional Reductions

Figure 45: Thresholded Image of Cross-Sectional Reductions

Figure 42: Inverted Image of cross-sectional Reductions
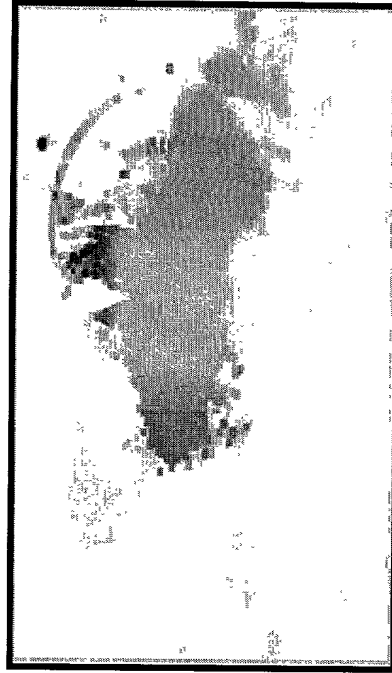
Figure 44: Background subtracted Image of Cross-sectional Reductions

Figure 46: Segmented Image of Cross-sectional Reductions

Results						
Area	Mean	S.D.	X	Y	Length	Major
1. 76.00	90.84	55.80	256.92	16.22	38.04	12.60
2. 17141.00	77.01	17.65	206.03	102.46	1347.63	196.15
3. 433.00	51.68	4.15	82.04	47.86	149.88	32.95
4. 63.00	49.22	2.34	70.62	47.83	36.38	13.25
5. 105.00	53.85	6.10	6.34	162.71	45.56	15.40

Figure 47: Analysis Results of an Image Depicting Cross-sectional Reductions

Figure 48: Classification Results of a Case Example on Cross-sectional Reductions
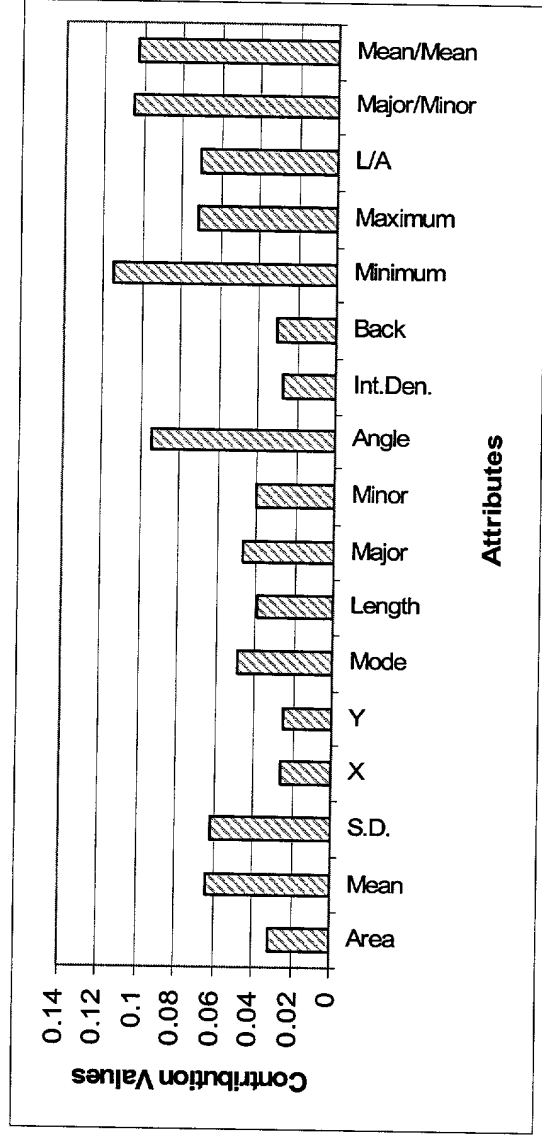
Table 49: Initial Parameters Used in Designing a Preliminary Neural Network for Classification of Misalignments
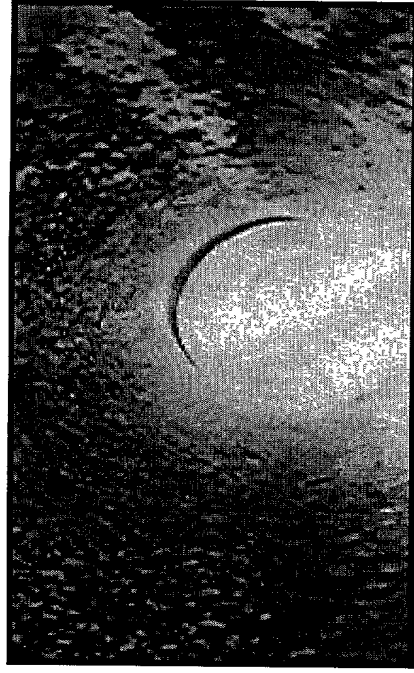
Figure 50: Inverted Image of Misalignments
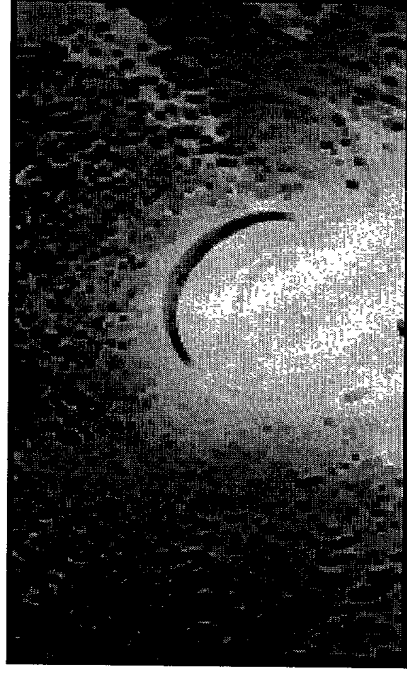
Figure 51: Dilated Image of Misalignments

Figure 52: Background Substracted Image of Misalignments

Figure 53: Thresholded Image of Misalignments
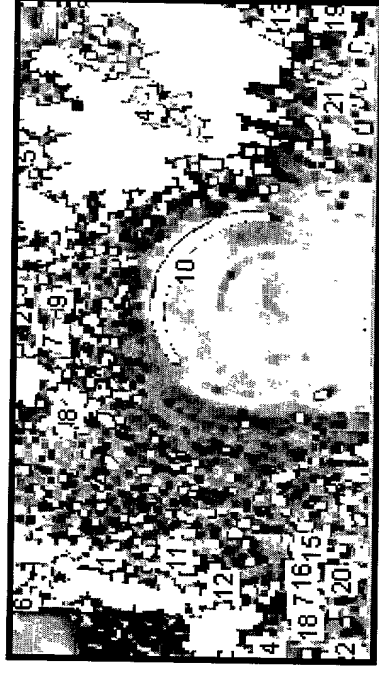
Figure 54: Segmented Image of Misalignments

	Area	Mean	S.D.	X	Y	Length	Major
1.	2661.00	47.26	8.76	45.90	42.65	940.85	92.06
2.	75.00	46.45	12.18	158.67	5.32	49.36	12.07
3.	73.00	46.25	9.46	171.18	3.55	48.28	15.81
4.	6979.00	65.86	23.03	254.26	56.42	1431.09	127.44
5.	151.00	50.42	10.84	234.46	6.10	76.77	16.84
6.	63.00	42.86	3.46	24.00	7.59	43.46	14.36
7.	147.00	52.41	17.64	148.17	18.16	73.60	16.54
8.	315.00	49.34	12.66	113.77	25.18	172.99	22.07
9.	77.00	45.30	10.39	166.31	20.26	51.46	11.32
10.	524.00	61.37	24.96	181.44	75.00	212.65	46.55
11.	77.00	44.99	6.90	47.45	72.77	49.46	16.56
12.	51.00	43.12	3.41	34.14	92.31	34.97	11.00
13.	96.00	61.27	22.01	303.91	113.18	44.73	15.06
14.	61.00	44.38	3.60	2.20	112.74	31.90	12.69
15.	186.00	51.23	16.69	52.42	129.34	115.15	19.32
16.	86.00	55.33	14.79	39.26	125.14	39.80	15.82
17.	82.00	43.87	5.03	25.78	126.00	52.87	15.35
18.	97.00	44.66	5.31	15.62	128.27	57.46	12.62
19.	187.00	53.84	19.02	302.75	136.37	98.77	24.82
20.	170.00	60.12	19.48	37.32	142.69	65.94	21.02
21.	59.00	60.66	30.58	262.57	136.07	33.21	10.31
22.	89.00	46.31	7.62	2.34	144.67	55.31	17.46

Figure 55: Analysis Results of an Image Depicting Misalignments

Figure 56: Classification Results of a Case example on Misalignments

Figure 57: Segmented Image of Deposits
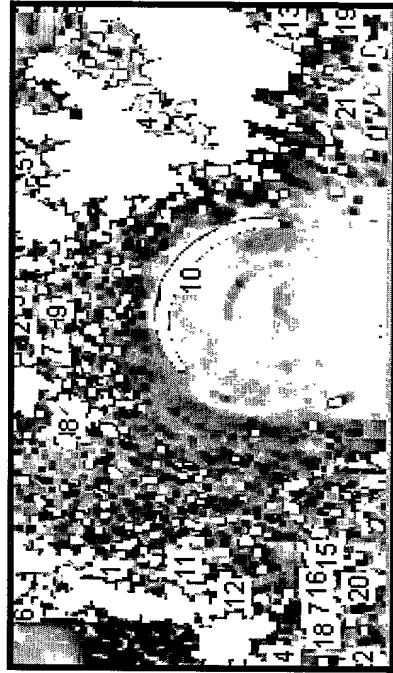
Figure 58: Segmented image of Misalignments

Figure 59: Segmented Image of Cross-sectional Reductions

Figure 60: Segmented Image of Cracks

Figure 61: Segmented Image of Infiltration

Number of row with variable names [blank if none]: [   ]   [X] left/right arrow keys and edit
First row containing actual training data: [1]   Size: 100 rows 20 columns

Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options mer "datagrid" for details.

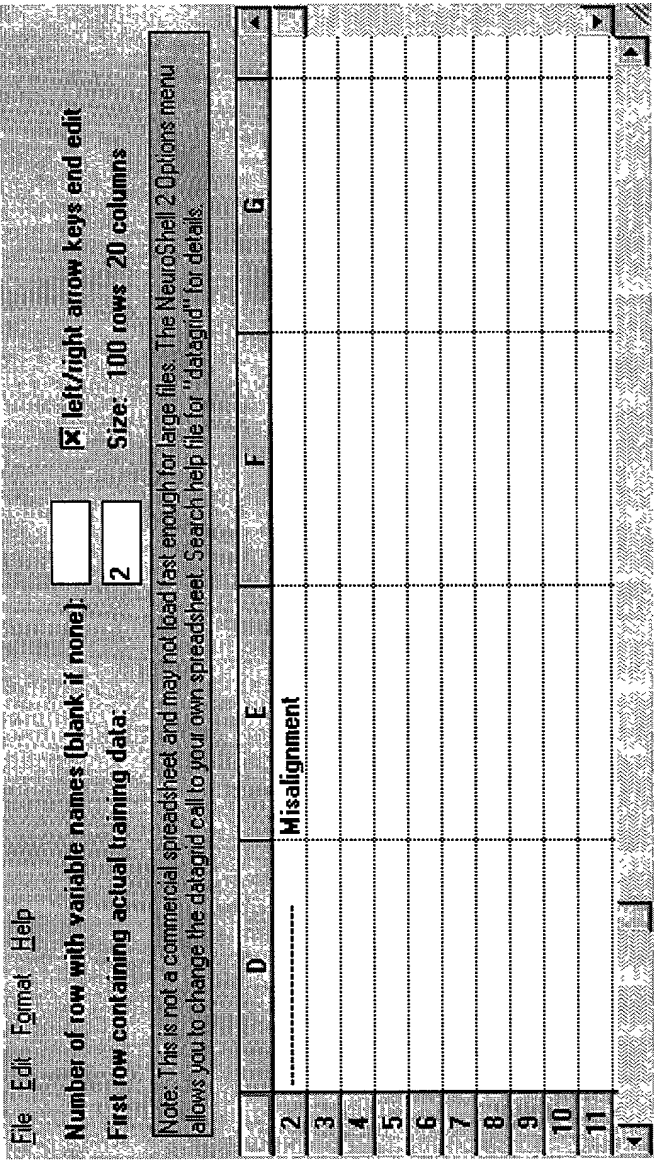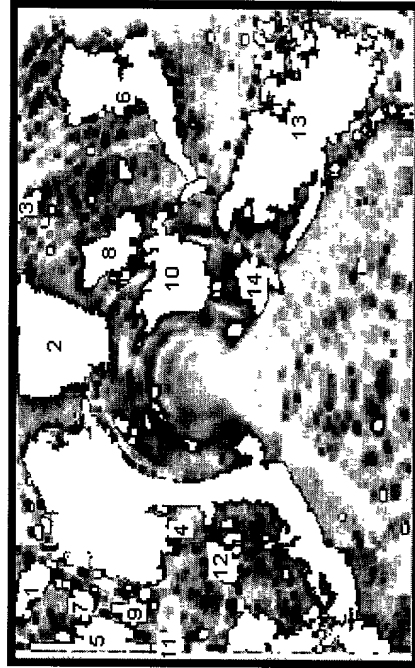|	D	E	F	G
1	Else	----------------		
2	Else	----------------		
3	Else	----------------		
4	----------------	Deposits		
5				
6				
7	Else	----------------		
8	Else	----------------		
9	Else	----------------		
10	Else	----------------		
11	Else	----------------		
12	Else	----------------		
13	Else	----------------		
14	Else	----------------		
15	Else	----------------		
16	Else	----------------		
17	Else	----------------		
18	Else	----------------		
19	Else	----------------		
20	Else	----------------		
21	Else	----------------		
22	Else	----------------		
23	Else	----------------		
24	Else	----------------		
25	Else	----------------		
26	Else	----------------		
27	Else	----------------		
28	Else	----------------		
29				
30				

Figure 62: Output Results of a Case Example on Deposits Utilizing DepositNet 1 and the Solution Strategy Module

	D	E	F	G
31	Else	----------------		
32	Else	----------------		
33	Else	----------------		
34	Else	----------------		
35	Else	----------------		
36				
37				
38	Else	----------------		
39	Else	----------------		
40	Else	----------------		
41	Else	----------------		
42	Else	----------------		
43	Else	----------------		
44	Else	----------------		
45	Else	----------------		
46	Else	----------------		
47	Else	----------------		
48	Else	----------------		
49	Else	----------------		
50	Else	----------------		
51	Else	----------------		
52				
53				
54	Else	----------------		
55	Else	----------------		
56	Else	----------------		
57	Else	----------------		
58	Else	----------------		
59	Else	----------------		
60				
61				

Figure 62: Output Results of a Case Example on Deposits Utilizing DepositNet 1 and the Solution Strategy Module (Continued)

File Edit Format Help

Number of row with variable names [blank if none]: [____]   ☒ left/right arrow keys end edit
First row containing actual training data: [1   ]   Size: 100 rows 20 columns

Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options men "datagrid" for details.

	D	E	F	G
1	Else	----------------		
2	Else	----------------		
3	Else	----------------		
4	----------------	Deposits		
5				
6				
7	Else	----------------		
8	Else	----------------		
9	Else	----------------		
10	Else	----------------		
11	Else	----------------		
12	Else	----------------		
13	Else	----------------		
14	Else	----------------		
15	Else	----------------		
16	Else	----------------		
17	Else	----------------		
18	Else	----------------		
19	Else	----------------		
20	Else	----------------		
21	Else	----------------		
22	Else	----------------		
23	Else	----------------		
24	Else	----------------		
25	Else	----------------		
26	Else	----------------		
27	Else	----------------		
28	Else	----------------		
29				

Figure 63: Output Results of a Case Example on Deposits Utilizing DepositNet 2 and the Solution Strategy Module

	D	E	F	G
30				
31	Else	----------------		
32	Else	----------------		
33	Else	----------------		
34	Else	----------------		
35	Else	----------------		
36				
37				
38	Else	----------------		
39	Else	----------------		
40	Else	----------------		
41	Else	----------------		
42	Else	----------------		
43	Else	----------------		
44	Else	----------------		
45	Else	----------------		
46	Else	----------------		
47	Else	----------------		
48	Else	----------------		
49	Else	----------------		
50	Else	----------------		
51	Else	----------------		
52				
53				
54	Else	----------------		
55	Else	----------------		
56	Else	----------------		
57	Else	----------------		
58	Else	----------------		
59	Else	----------------		
60				

Figure 63: Output Results of a Case Example on Deposits Utilizing DepositNet 2 and the Solution Strategy Module (Continued)

File   Edit   Format   Help
Number of row with variable names (blank if none):
First row containing actual training data:
[X left/right arrow keys and edit
Size: 100 rows 20 columns
Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options mer
"datagrid" for details.

	D	E	F	G
1	Else			
2	Else			
3	Else			
4		Deposits		
5				
6				
7	Else			
8	Else			
9	Else			
10	Else			
11	Else			
12	Else			
13	Else			
14	Else			
15	Else			
16	Else			
17	Else			
18	Else			
19	Else			
20	Else			
21	Else			
22	Else			
23	Else			
24	Else			
25	Else			
26	Else			
27	Else			
28	Else			

Figure 64: Output Results of a Case Example on Deposits Utilizing DepositNet 3 and the Solution Strategy Module

	D	E	F	G
29				
30				
31	Else			
32	Else			
33	Else			
34	Else			
35	Else			
36				
37				
38	Else			
39	Else			
40	Else			
41	Else			
42	Else			
43	Else			
44	Else			
45	Else			
46	Else			
47	Else			
48	Else			
49	Else			
50	Else			
51	Else			
52				
53				
54	Else			
55	Else			
56	Else			
57	Else			
58	Else			
59	Else			

Figure 64: Output Results of a Case Example on Deposits Utilizing DepositNet 3 and the Solution Strategy Module (Continued)

	AA	AB	AC	AD	AE	AF	AG	AH
1					Else			
2					Else			
3					Else			
4					Deposits			
5								
6								
7					Else			
8					Else			
9					Else			
10					Else			
11					Else			
12					Else			
13					Else			
14					Else			
15					Else			
16					Else			
17					Else			
18					Else			
19					Else			
20					Else			
21					Else			
22					Else			
23					Else			
24					Else			
25					Else			
26					Else			
27					Else			
28					Else			

Figure 65: Comparison of Output Results of DepositNet 1-3 Utilizing the Multiple Classifier Module

	AA	AB	AC	AD	AE	AF	AG	AH
31					Else			
32					Else			
33					Else			
34					Else			
35					Else			
36								
37								
38					Else			
39					Else			
40					Else			
41					Else			
42					Else			
43					Else			
44					Else			
45					Else			
46					Else			
47					Else			
48					Else			
49					Else			
50					Else			
51					Else			
52								
53								
54					Else			
55					Else			
56					Else			
57					Else			
58					Else			
59					Else			

Figure 65: Comparison of Output Results of DepositNet 1-3 Utilizing the Multiple Classifier Module (Continued)

File Edit Format Help

Number of row with variable names (blank if none):

First row containing actual training data:

☒ left/right arrow keys end edit

Size: 100 rows 20 columns

1

Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options menu allows you to change the datagrid call to your own spreadsheet. Search help file for "datagrid" for details.

	D	E	F	G
1	Cross-sectional reduction			
2				
3				
4	Cross-sectional reduction			
5				
6				
7				
8				
9				
10				

Figure 66: Output Results of a Case Example on Cross-sectional Reductions Utilizing CrossNet 1 and the Solution Strategy

File Edit Format Help

Number of row with variable names [blank if none]:

[X] left/right arrow keys end edit

First row containing actual training data: 1   Size: 100 rows 20 columns

Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options menu allows you to change the datagrid call to your own spreadsheet. Search help file for "datagrid" for details

	D	E	F	G
1		Else		
2				
3				
4	Cross-sectional reduction			
5				
6				
7				
8				
9				
10				

Figure 67: Output Results of a Case Example on Cross-sectional Reductions Utilizing CrossNet 2 and the Solution Strategy

File Edit Format Help

Number of row with variable names (blank if none): [   ]   [X] left/right arrow keys end edit

First row containing actual training data: [1   ]   Size: 100 rows 20 columns

Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options menu allows you to change the datagrid call to your own spreadsheet. Search help file for "datagrid" for details.

	D	E	F	G
1	--------------------	Else		
2				
3				
4	Cross-sectional reductions	--------------------		
5				
6				
7				
8				
9				
10				

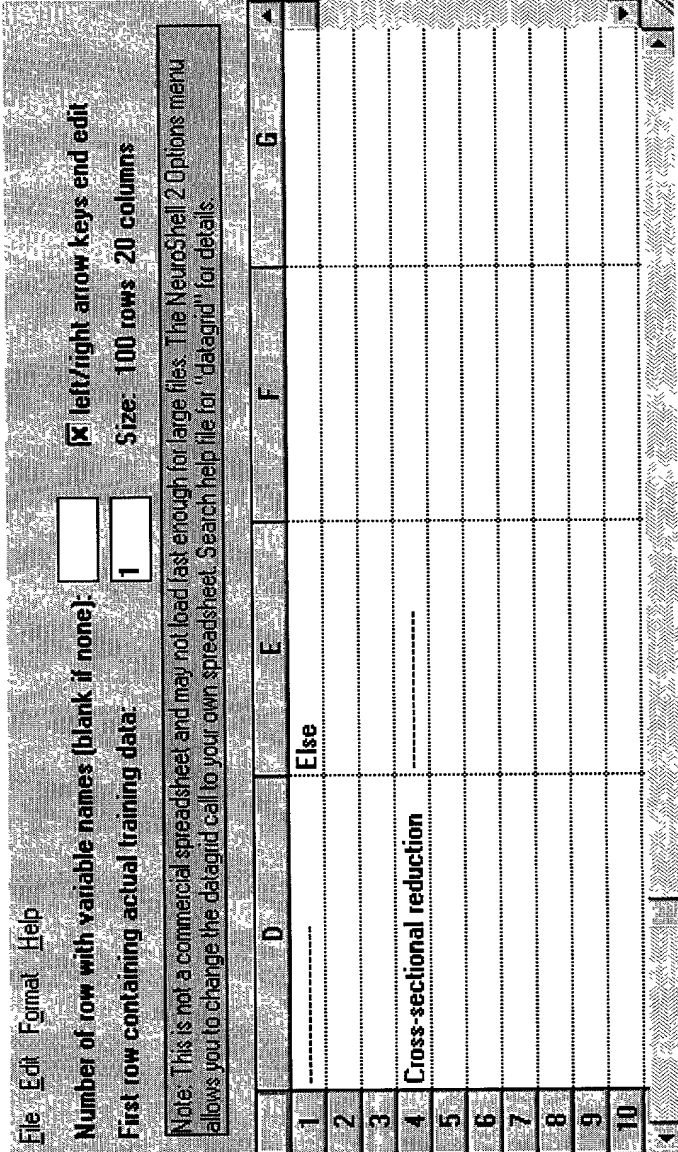**Figure 68: Output Results of a Case Example on Cross-sectional Reductions Utilizing CrossNet 3 and the Solution Strategy Module**

Figure 69: Comparison of Output Results of CrossNet 1-3 Utilizing the Multiple Classifier Module

File Edit Format Help

Number of row with variable names (blank if none): [   ]   ☒ left/right arrow keys end edit

First row containing actual training data: [1   ]   Size: 100 rows 20 columns

Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options menu allows you to change the datagrid call to your own spreadsheet. Search help file for "datagrid" for details.

	D	E	F	G	
1	-----------------------	Misalignment			
2					
3					
4	Else	-----------------------			
5					
6					
7					
8					
9					
10					

Figure 70: Output Results of a Case Example on Misalignments Utilizing MisalignmentNet 1 and the Solution Strategy Module

File Edit Format Help

Number of row with variable names (blank if none): [   ]   ☒ left/right arrow keys end edit

First row containing actual training data: [1   ]   Size: 100 rows 20 columns

Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options menu allows you to change the datagrid call to your own spreadsheet. Search help file for "datagrid" for details.

	D	E	F	G	
1	-----------------------	Misalignment			
2					
3					
4	Else	-----------------------			
5					
6					
7					
8					
9					
10					
11					

Figure 71: Output Results of a Case Example on Misalignments Utilizing MisalignmentNet 2 and the Solution Strategy Module

Number of row with variable names (blank if none): [ ]   ☒ left/right arrow keys end edit

First row containing actual training data: [1]   Size: 100 rows 20 columns

Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options menu allows you to change the datagrid call to your own spreadsheet. Search help file for "datagrid" for details.

	D	E	F	G	
1	--------------------	Misalignment			
2					
3					
4	--------------------	--------------------			
5					
6					
7					
8					
9					
10					

Figure 72: Output Results of a Case Example on Misalignments Utilizing MisalignmentNet 3 and the Solution Strategy

	AA	AB	AC	AD	AE	AF	AG
1					Misalignment		
2							
3							
4		equal		Else			
5							
6							
7							
8							
9							
10							

Figure 73: Comparison of Output Results of MisalignmentNet 1-3 Utilizing the Multiple Classifier Module

Figure 75: Segmented Image of Cross-sectional Reductions

Figure 77: Segmented image of Deposits

Figure 74: Segmented Image of Cracks
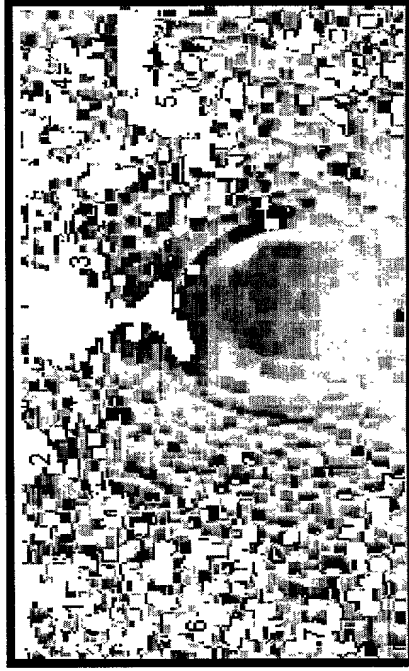
Figure 76:Segmented Image of Misalignments
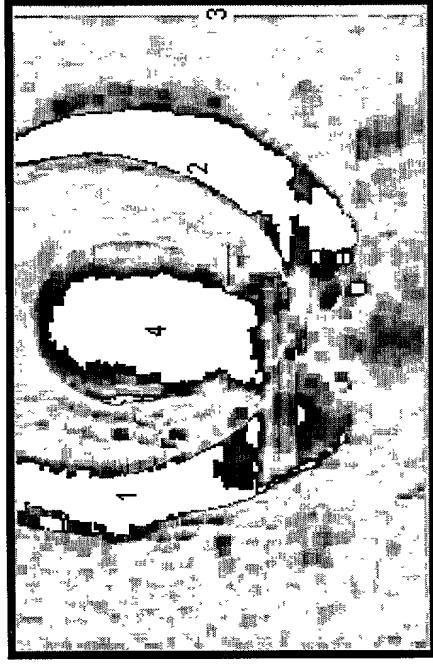
Figure 78: Segmented Image of Infiltration

Number of row with variable names (blank if none): [   ]   X left/right arrow keys end edit

First row containing actual training data: [1   ]   Size: 100 rows 20 columns

Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options men "datagrid" for details.

	D	E	F	G
1	------------	Else		
2	------------	Else		
3	------------	Else		
4	------------	Else		
5	------------	Else		
6	------------	Else		
7				
8				
9	------------	Else		
10	------------	Else		
11	------------	Else		
12	------------	Else		
13	------------	Else		
14	------------	Else		
15	------------	Else		
16				
17				

Figure 79: Output Results of a Case Example on Infiltration Utilizing InfiltrationNet 1 and the Solution Strategy Module

	D	E	F	G
18	------------	Else		
19	------------	Else		
20	------------	Else		
21	------------	Else		
22	Infiltration	------------		
23	------------	Else		
24	------------	Else		
25				
26				
27	------------	Else		
28	------------	Else		
29	------------	Else		
30				
31				
32	Infiltration	------------		
33	Infiltration	------------		
34	------------	Else		
35	------------	Else		
36				

Figure 79: Output Results of a Case Example on Infiltration Utilizing InfiltrationNet 1 and the Solution Strategy Module (Continued)

Number of row with variable names (blank if none): ☐   ☒ left/right arrow keys end edit

First row containing actual training data: `1`   Size: 100 rows 20 columns

Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options men "datagrid" for details.

	D	E	F	G
1	-----------------	Else		
2	-----------------	Else		
3	-----------------	Else		
4	Infiltration	-----------------		
5	-----------------	Else		
6	-----------------	Else		
7				
8				
9	-----------------	Else		
10	-----------------	Else		
11	-----------------	Else		
12	-----------------	Else		
13	-----------------	Else		
14	-----------------	Else		
15	-----------------	Else		
16				

Figure 80: Output Results of a Case Example on Infiltration Utilizing InfiltrationNet 2 and the Solution Strategy Module

	D	E	F	G
17				
18	-----------------	Else		
19	-----------------	Else		
20	-----------------	Else		
21	-----------------	Else		
22	-----------------	Else		
23	-----------------	Else		
24	-----------------	Else		
25				
26				
27	-----------------	Else		
28	Infiltration	-----------------		
29	-----------------	Else		
30				
31				
32	Infiltration	-----------------		
33	Infiltration	-----------------		
34	-----------------	Else		
35	-----------------	Else		
36				
37				

Figure 80: Output Results of a Case Example on Infiltration Utilizing InfiltrationNet 2 and the Solution Strategy Module (Continued)

Number of row with variable names (blank if none): ☐   ☒ left/right arrow keys end edit

First row containing actual training data: `1`   Size: 100 rows 20 columns

Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options menu "datagrid" for details.

	D	E	F	G
1	Infiltration	----------------		
2	----------------	Else		
3	----------------	Else		
4	----------------	Else		
5	----------------	Else		
6	----------------	Else		
7				
8				
9	----------------	Else		
10	----------------	Else		
11	----------------	Else		
12	----------------	Else		
13	----------------	Else		
14	----------------	Else		
15	----------------	Else		
16				
17				

Figure 81: Output Results of a Case Example on Infiltration Utilizing InfiltrationNet 3 and the Solution Strategy Module

	D	E	F	G
18	----------------	Else		
19	----------------	Else		
20	----------------	Else		
21	----------------	Else		
22	----------------	Else		
23	----------------	Else		
24	----------------	Else		
25				
26				
27	----------------	Else		
28	----------------	Else		
29	----------------	Else		
30				
31				
32	Infiltration	----------------		
33	Infiltration	----------------		
34	----------------	Else		
35	----------------	Else		
36				
37				
38				

Figure 81: Output Results of a Case Example on Infiltration Utilizing InfiltrationNet 3 and the Solution Strategy Module (Continued)

	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL
1			Else							
2			Else							
3			Else							
4		equal				Else				
5			Else							
6			Else							
7										
8										
9			Else							
10			Else							
11			Else							
12			Else							
13			Else							
14			Else							
15			Else							
16										
17										

Figure 82: Comparison of Output Results of InfiltrationNet 1-3 Utilizing the Multiple Classifier Module

	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL
18			Else							
19			Else							
20			Else							
21			Else							
22		equal								Else
23			Else							
24			Else							
25										
26										
27			Else							
28		equal				Else				
29			Else							
30										
31										
32			Infiltration							
33			Infiltration							
34			Else							
35			Else							
36										

Figure 82: Comparison of Output Results of InfiltrationNet 1-3 Utilizing the Multiple Classifier Module (Continued)

Figure 84: Segmented Image of Cross-sectional Reductions

Figure 83: Segmented Image of Cracks

Figure 85: Segmented Image of Misalignments

Figure 87: Segmented Image of Infiltration

Figure 86: Segmented Image of Deposits

Number of row with variable names (blank if none): [   ]   [X] left/right arrow keys end edit
First row containing actual training data. [1]   Size: 100 rows 20 columns
Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options menu "datagrid" for details.

	D	E	F	G
1	----------------	Else		
2	----------------	Else		
3	----------------	Else		
4	----------------	Else		
5	----------------	Else		
6	----------------	Else		
7	----------------	Else		
8	Crack	----------------		
9	----------------	Else		
10	----------------	Else		
11	----------------	Else		
12	Crack	----------------		
13	----------------	Else		
14	----------------	Else		
15	----------------	Else		
16				
17				
18	----------------	Else		
19	----------------	Else		
20	----------------	Else		
21	----------------	Else		
22				

Figure 88: Output Results of a Case Example on Cracks Utilizing CrackNet 1 and the Solution Strategy Module

	D	E	F	G
23				
24	----------------	Else		
25	----------------	Else		
26				
27				
28	Crack	----------------		
29	----------------	Else		
30				
31				
32	----------------	Else		
33	Crack	----------------		
34	----------------	Else		
35	----------------	Else		
36	----------------	Else		
37	----------------	Else		
38	----------------	Else		
39	----------------	Else		
40	----------------	Else		
41				
42				
43				

Figure 88: Output Results of a Case Example on Cracks Utilizing CrackNet 1 and the Solution Strategy Module (Continued)

Number of row with variable names (blank if none): [   ]   ☒ left/right arrow keys end edit
First row containing actual training data: [1   ]   Size: 100 rows 20 columns

Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options men "datagrid" for details.

	D	E	F	G
1	-------------	Else		
2	-------------	Else		
3	-------------	Else		
4	-------------	Else		
5	-------------	Else		
6	-------------	Else		
7	-------------	Else		
8	Crack	-------------		
9	-------------	Else		
10	-------------	Else		
11	-------------	Else		
12	Crack	-------------		
13	-------------	Else		
14	-------------	Else		
15	Crack	-------------		
16				
17				
18	-------------	Else		
19	-------------	Else		
20	-------------	Else		
21	-------------	Else		
22				
23				

Figure 89: Output Results of a Case Example on Cracks Utilizing CrackNet 2 and the Solution Strategy Module

	D	E	F	G
24	Crack	-------------		
25	-------------	Else		
26				
27				
28	-------------	Else		
29	-------------	Else		
30				
31				
32	-------------	Else		
33	Crack	-------------		
34	-------------	Else		
35	-------------	Else		
36	-------------	Else		
37	-------------	Else		
38	-------------	Else		
39	-------------	Else		
40	-------------	Else		
41				
42				

Figure 89: Output Results of a Case Example on Cracks Utilizing CrackNet 2 and the Solution Strategy Module (Continued)

File Edit Format Help

Number of row with variable names (blank if none): [ ]   ☒ left/right arrow keys end edit
First row containing actual training data: [1]   Size: 100 rows 20 columns

Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options men "datagrid" for details.

	D	E	F	G
1	------------------	Else		
2	------------------	Else		
3	------------------	Else		
4	------------------	Else		
5	------------------	Else		
6	------------------	Else		
7	------------------	Else		
8	Crack	------------------		
9	------------------	Else		
10	------------------	Else		
11	------------------	Else		
12	Crack	------------------		
13	------------------	Else		
14	------------------	Else		
15	Crack	------------------		
16				
17				
18	------------------	Else		
19	------------------	Else		
20	------------------	Else		
21	------------------	Else		

Figure 90: Output Results of a Case Example on Cracks Utilizing CrackNet 3 and the Solution Strategy Module

	D	E	F	G
22				
23				
24	------------------	Else		
25	------------------	Else		
26				
27				
28	------------------	Else		
29	------------------	Else		
30				
31				
32	------------------	Else		
33	Crack	------------------		
34	------------------	Else		
35	------------------	Else		
36	------------------	Else		
37	------------------	Else		
38	------------------	Else		
39	------------------	Else		
40	------------------	Else		
41				
42				

Figure 90: Output Results of a Case Example on Cracks Utilizing CrackNet 3 and the Solution Strategy Module (Continued)

	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL
1				Else							
2				Else							
3				Else							
4				Else							
5				Else							
6				Else							
7				Else							
8				Crack							
9				Else							
10				Else							
11				Else							
12				Crack							
13				Else							
14				Else							
15		equal									Crack
16											
17											
18				Else							
19				Else							
20				Else							
21				Else							
22											

Figure 91: Comparison of Output Results of CrackNet 1-3 Utilizing the Multiple Classifier Module

	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL
23											
24		equal					Else				
25				Else							
26											
27											
28		equal									Else
29				Else							
30											
31											
32				Else							
33				Crack							
34				Else							
35				Else							
36				Else							
37				Else							
38				Else							
39				Else							
40				Else							
41											

Figure 91: Comparison of Output Results of CrackNet 1-3 Utilizing the Multiple Classifier Module (Continued)
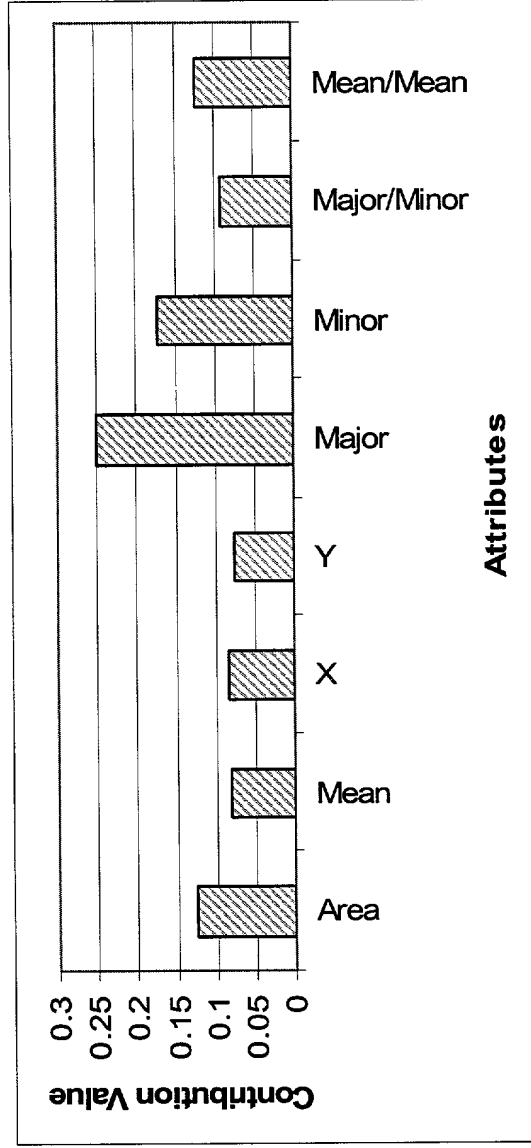
Figure 108: Contribution Values of Attributes Utilized in Designing InfiltrationNet 2
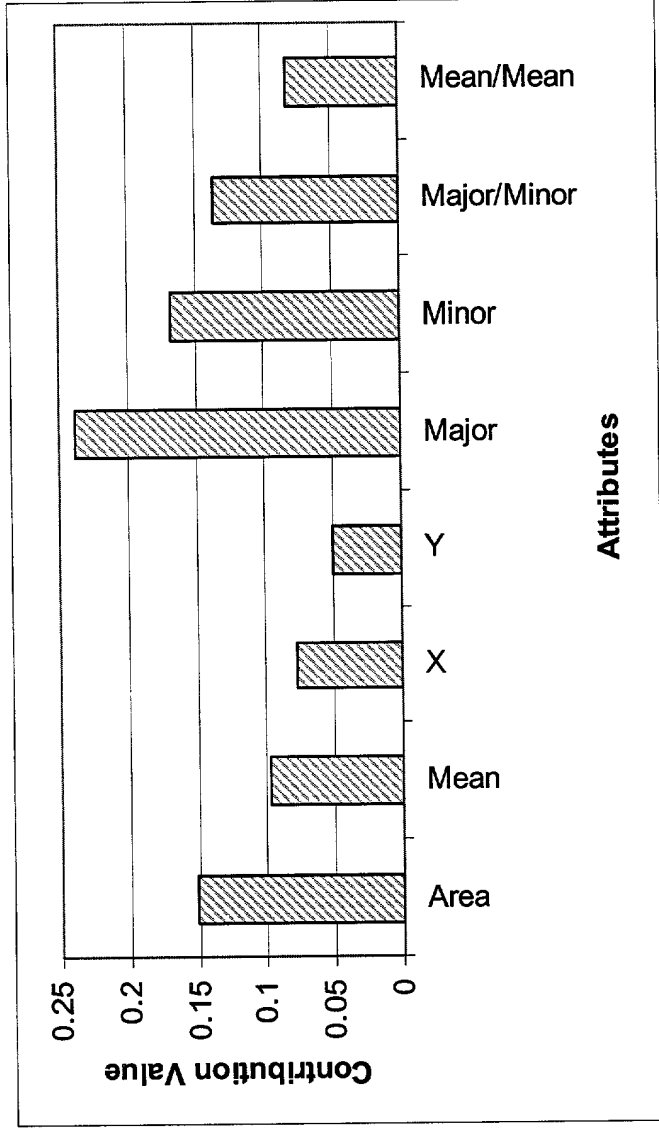
Figure 109: Contribution Values of Attributes Utilized in Designing InfiltrationNet 3
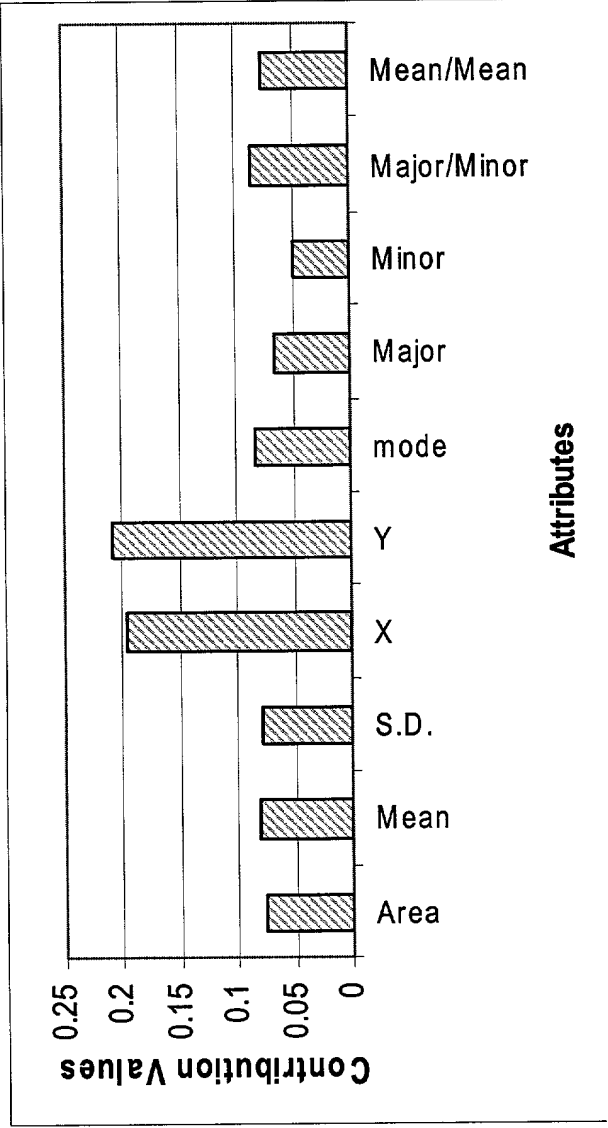
Figure 110: Contribution Values of Attributes Utilized in Designing DepositNet 2
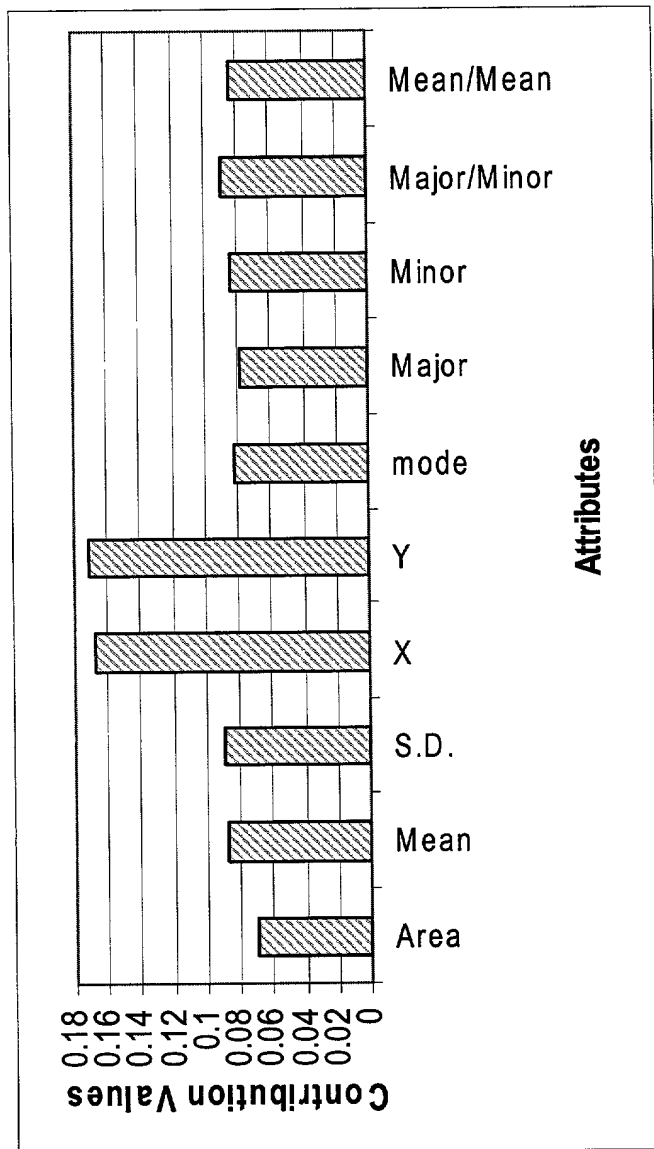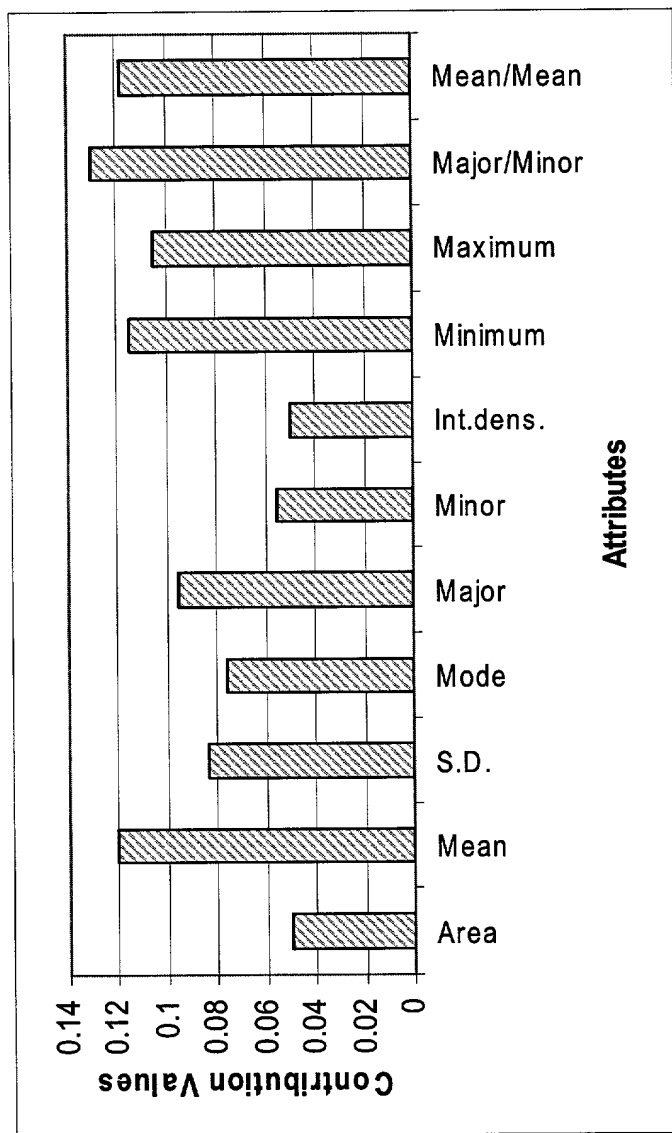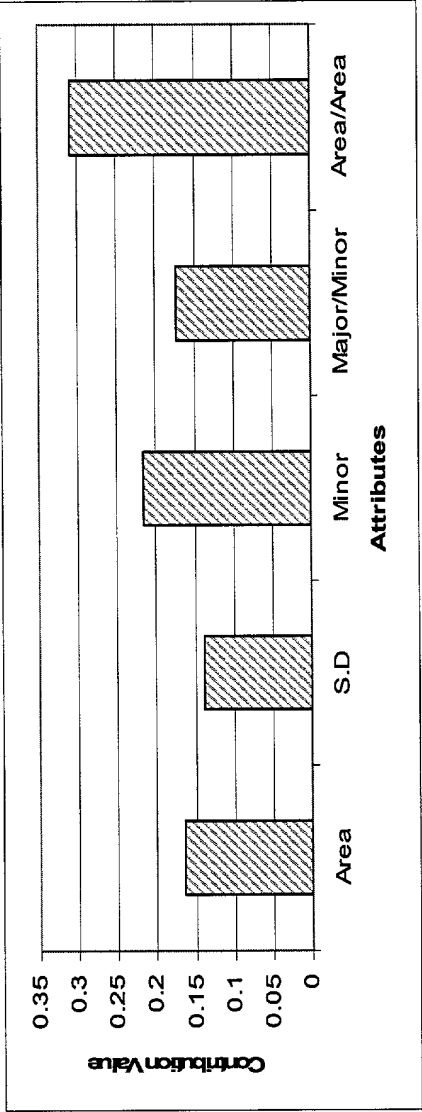
Figure 111: Contribution Values of Attributes Utilized in Designing DepositNet 3
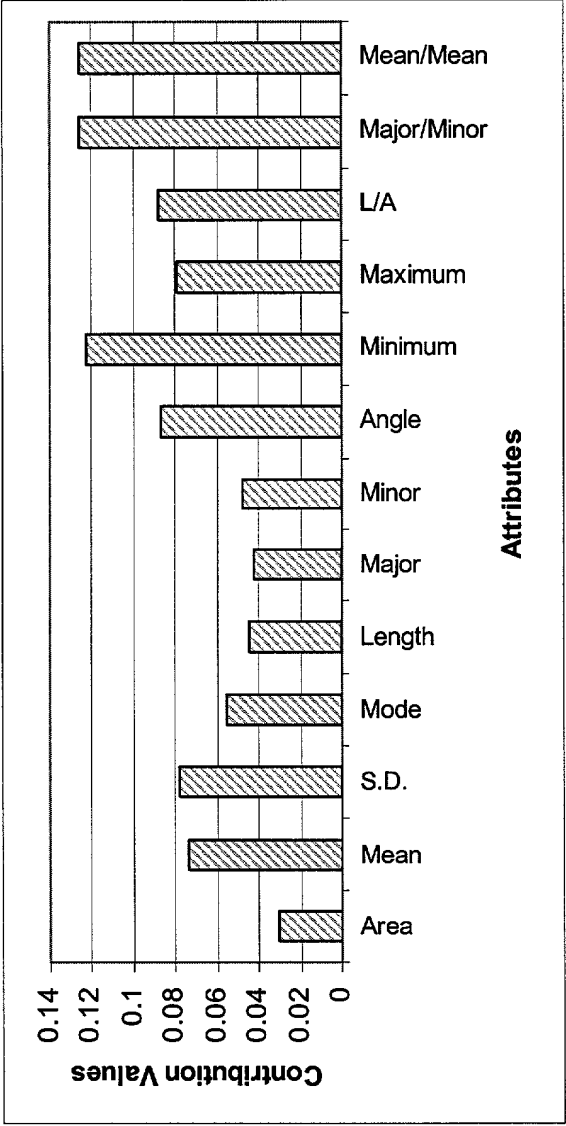
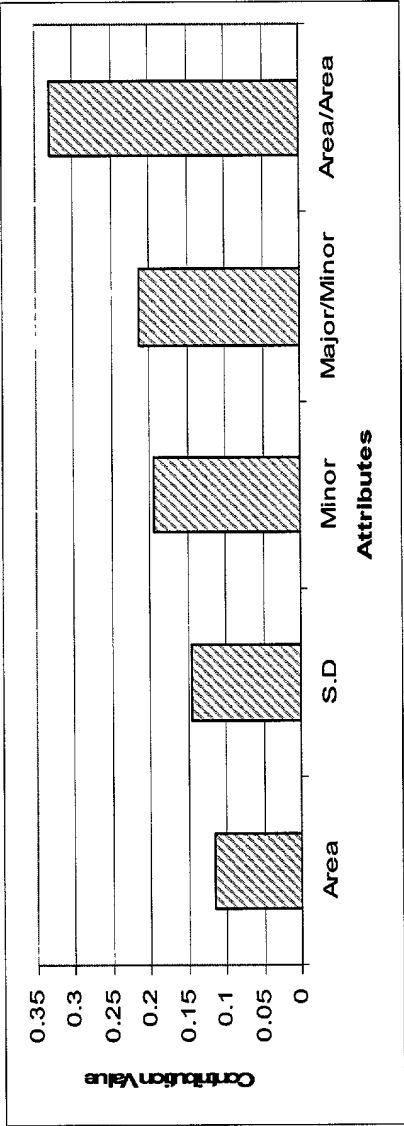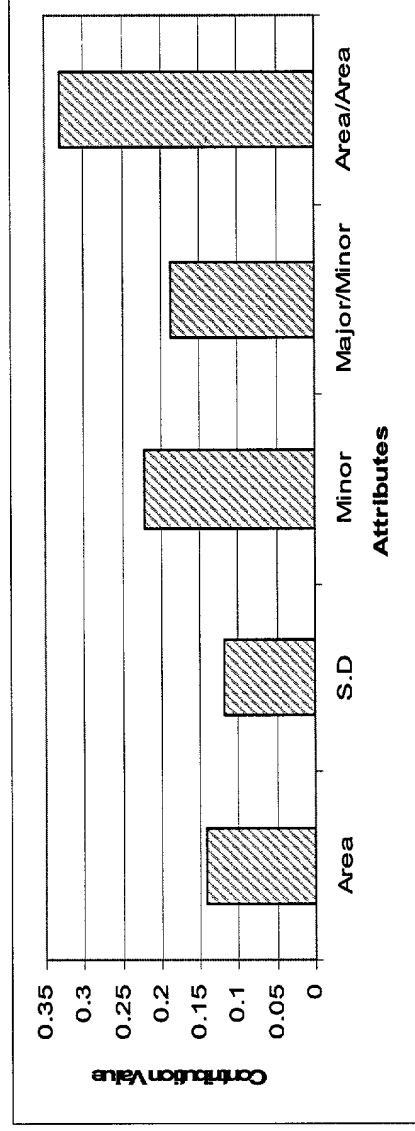**Figure 112: Contribution Values of Attributes Utilized in Designing CrossNet 1**
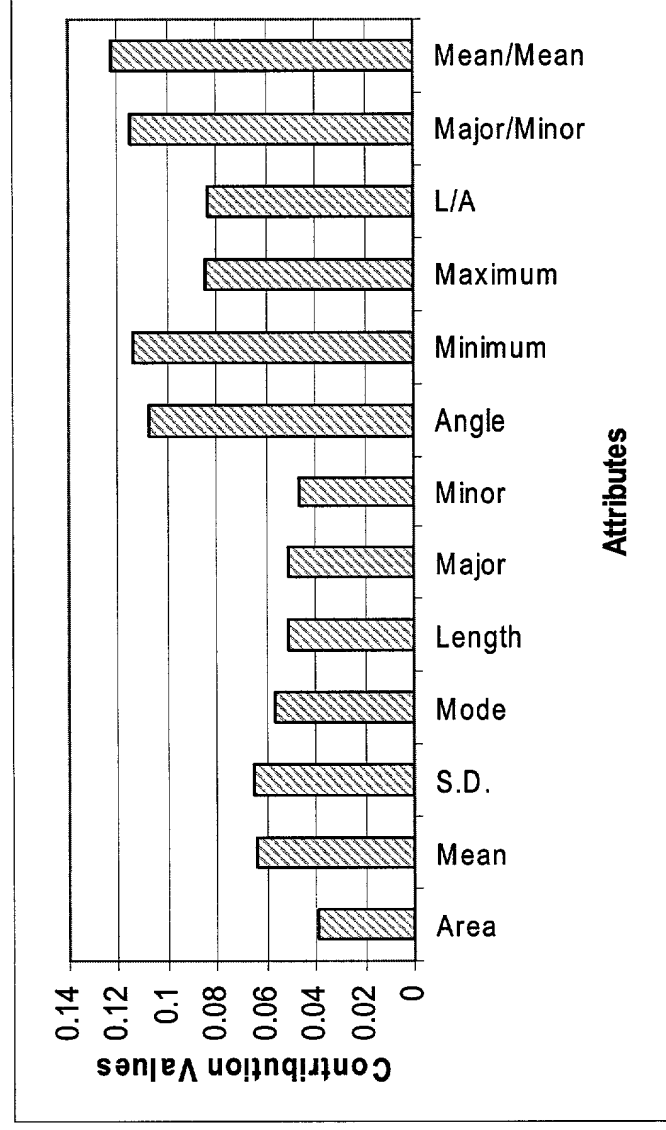
Figure 113: Contribution Values of Attributes Utilized in Designing CrossNet 2
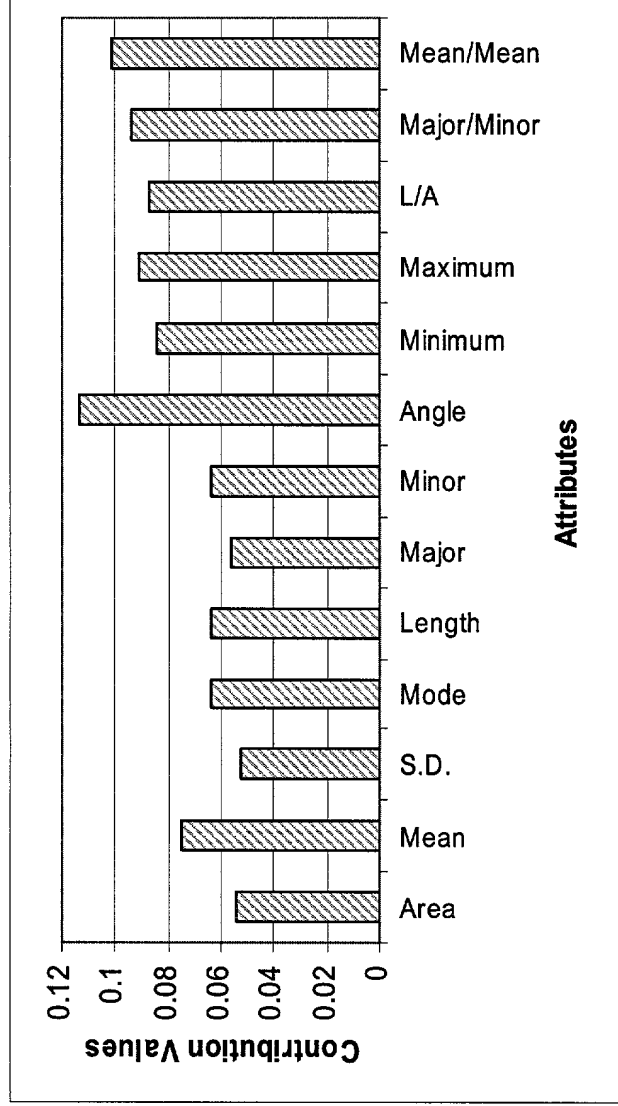
Figure 114: Contribution Values of Attributes Utilized in Designing CrossNet 2
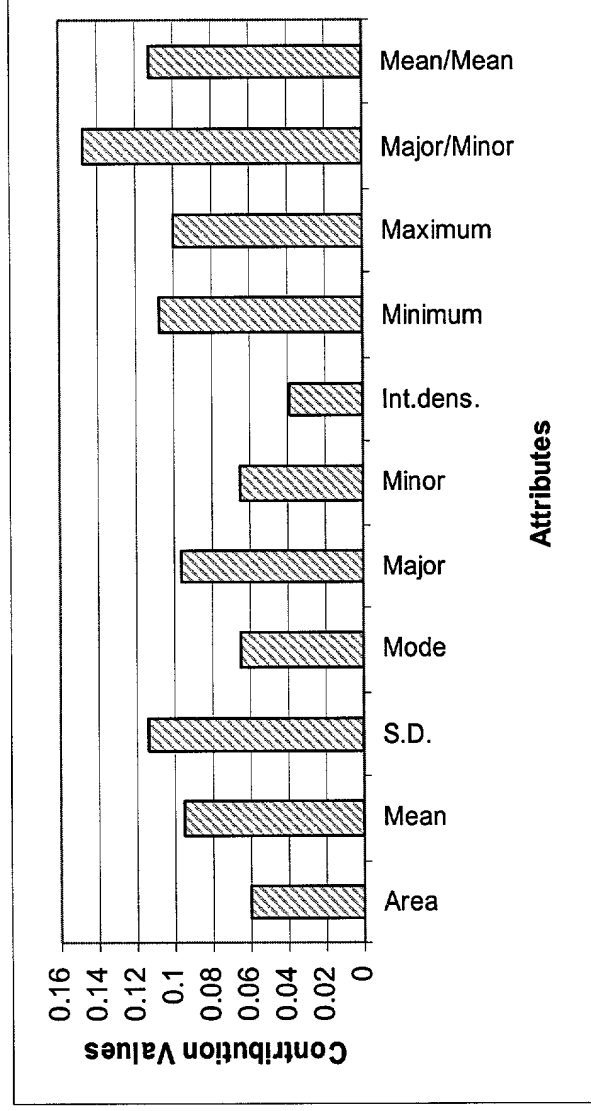
Figure 115: Contribution Values of Attributes Utilized in Designing
AlignmentNet 1
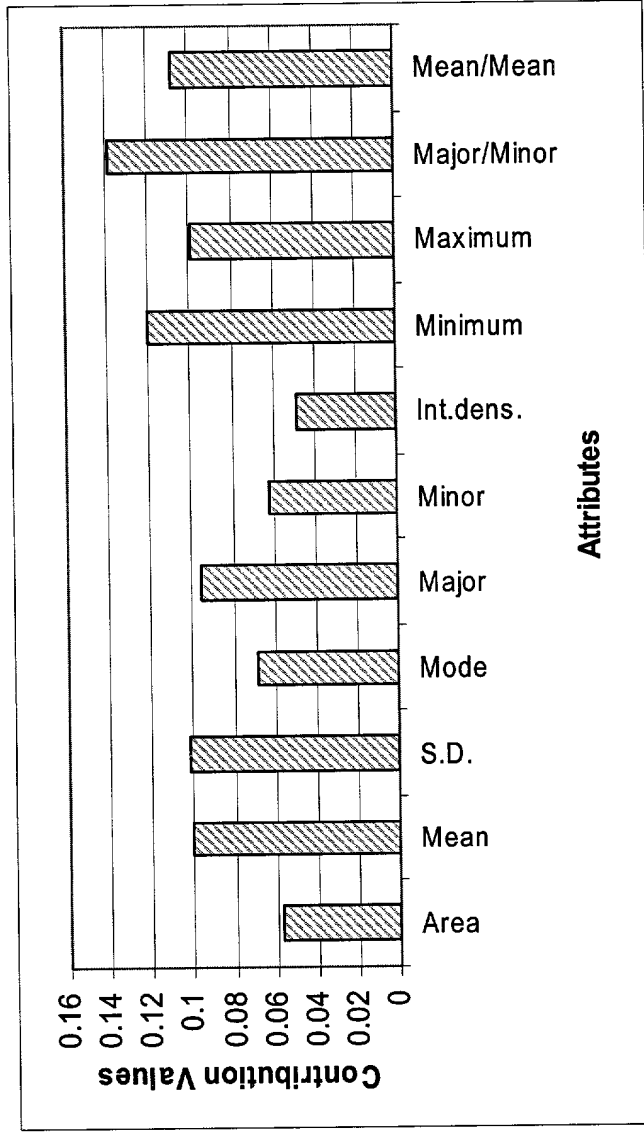
Figure 116: Contribution Values of Attributes Utilized in Designing AlignmentNet 2

Figure 117: Contribution Values of Attributes Utilized in Designing AlignmentNet 3

Figure 118: Contribution Values of Attributes Utilized in Designing ModCrossNet 1

Figure 119: Contribution Values of Attributes Utilized in Designing ModCrossNet 2

Figure 120: Contribution Values of Attributes Utilized in Designing ModCrossNet 3
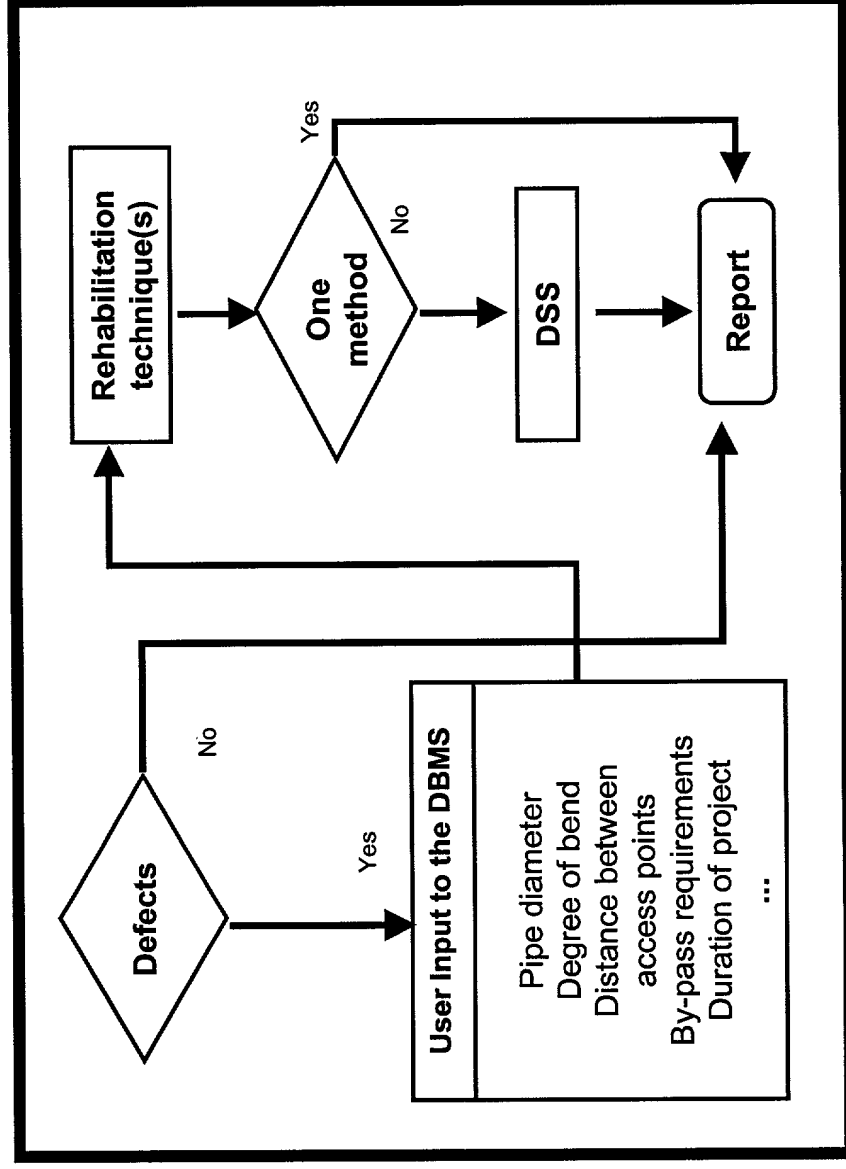
Figure 4-1: Developed Rehabilitation system

Field Name	Data Type	Description
ProductID	AutoNumber	Database serial number
Method of repair	Text	Commercial name of rehabilitation technique
Maximum distance between access points	Number	Maximum allowable distance between access points to the host pipe
Maximum degree of bends	Number	Maximum degree of bends of the host pipe
Average cost	Number	Cost of product
Average duration	Number	Duration to install 500 (m) of pipe in weeks
Number of years in business	Number	Years in business of supplier
Life expectency	Number	Design life of new pipe
Local experience	Text	Does the supplier have an Office in Canada
Access type	Text	Type of access required to the host pipe
Length of product installed	Number	Number of KM of product installed by the supplier
Inovation	Number	Ability of supplier to accomodate none stsndard designs
Coordinates	Number	Phone number

Field Properties

General | Lookup |

Field Size	Long Integer
New Values	Increment
Format	
Caption	Product ID
Indexed	Yes (No Duplicates)

A field name can be up to 64 characters long, including spaces. Press F1 for help on field names.

Figure 4-2: Products Table
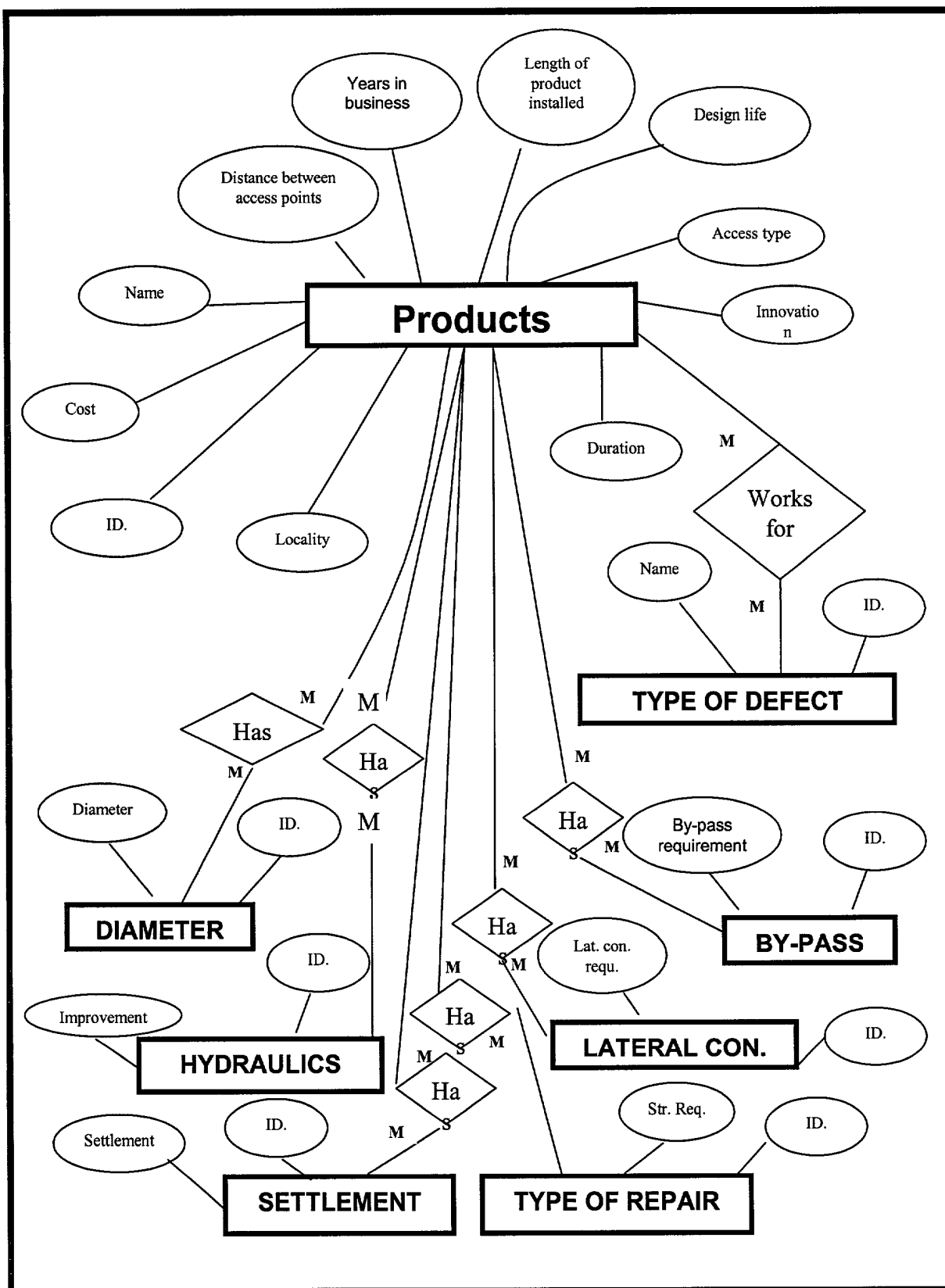
Figure 4-3: Entity Relationship Diagram

Defect
Defect ID
Defect name

Settlement
SettlementID
Accomodate future sett

Service conection
Service conectionID
Service Conection

by-pass requirements1
by-passID
by-pass requirements

Diameter
Diameter ID
Diameter

Structural requirement
StructuralID
Structural requirement

Hydraulics1
Hydraulics1ID
Hydraulics

Junction
Defect ID
Product ID

Junction5
Product ID
SettlementID

Junction6
Service conection
Product ID

Junction7
by-passID
Product ID

Junction1
Diameter ID
Product ID

Junction3
ProductID
StructuralID

Junction2
Hydraulics1ID
ProductID

Product
ProductID
Method of repair
Maximum distance between access points
Maximum degree of bends
Average cost
Average duration
Number of years in business
Life expectency
Local experience
Access type
Length of product installed
Inovation

Figure 4-4: Schema of the Developed Database

Figure 4-5: Database Execution Form

R E S U L T S

Diameter   [in/cm]

Defect name

Structural requirement   (structural/ non-structural)

Average cost   [$/cm of diameter/m of length]

Maximum degree of bends   [Degrees]

Access type   (manhole/ manhole&exca.pits)

Maximum distance between access points   [m]

Hydraulics   (improved/not improved)

by-pass requirements   (yes/no)

Average duration   (weeks)

Number of years in business   (years)

Length of product installed   [km]

Life expectency   (years)

Local experience   (yes/no)

Accomodate future settlement   (yes/no)

Inovation   (1-5)

Service Correction   (exc. is require/not required)

Non-structural
structural

Method of repair

Coordinates

Look for

Figure 4-6: Data Entry and Retrieval Form

UserForm20

Which attributes do you want to consider in your analysis

☐ Cost

☐ Years in business

☐ Duration

☐ Length of product installed

☐ Life expectancy

☐ Innovation

Next

Figure 4-7: Available Attributes to Users

Figure 4-8: Sample Dialog Screen
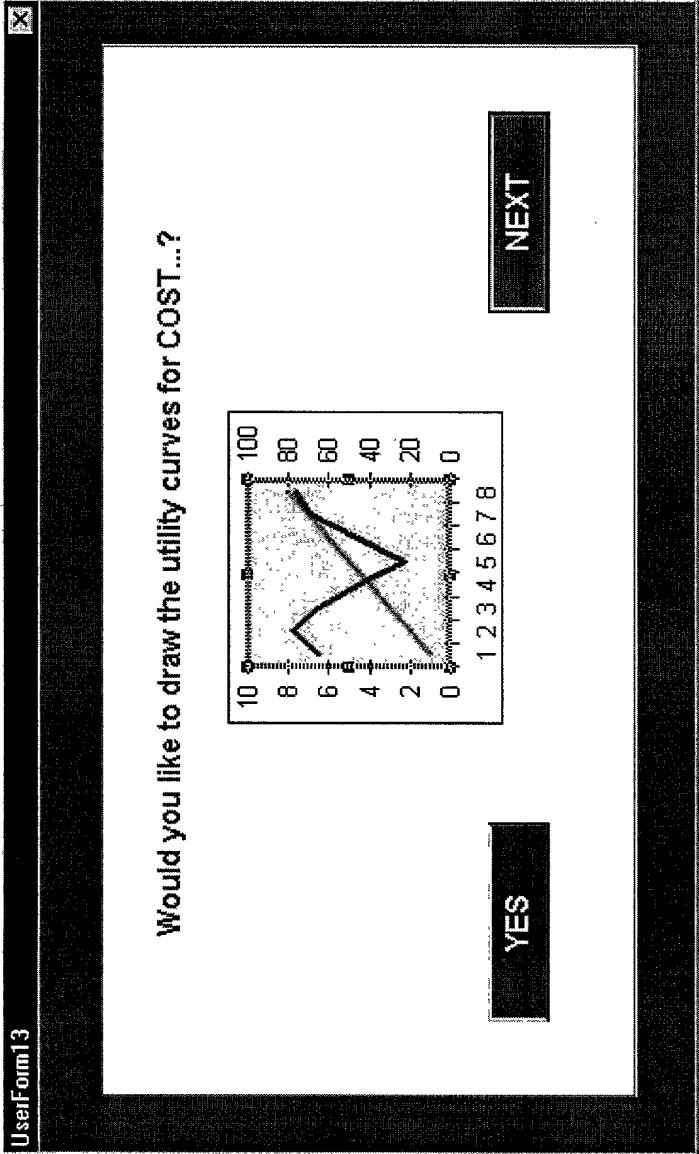
Figure 4-9: Plotting of Utility Functions

Figure 4-10: Selection of Utility Functions

UserForm200

Using a pre-defined set of weights   C

Or

The system is to calculate the weights   C
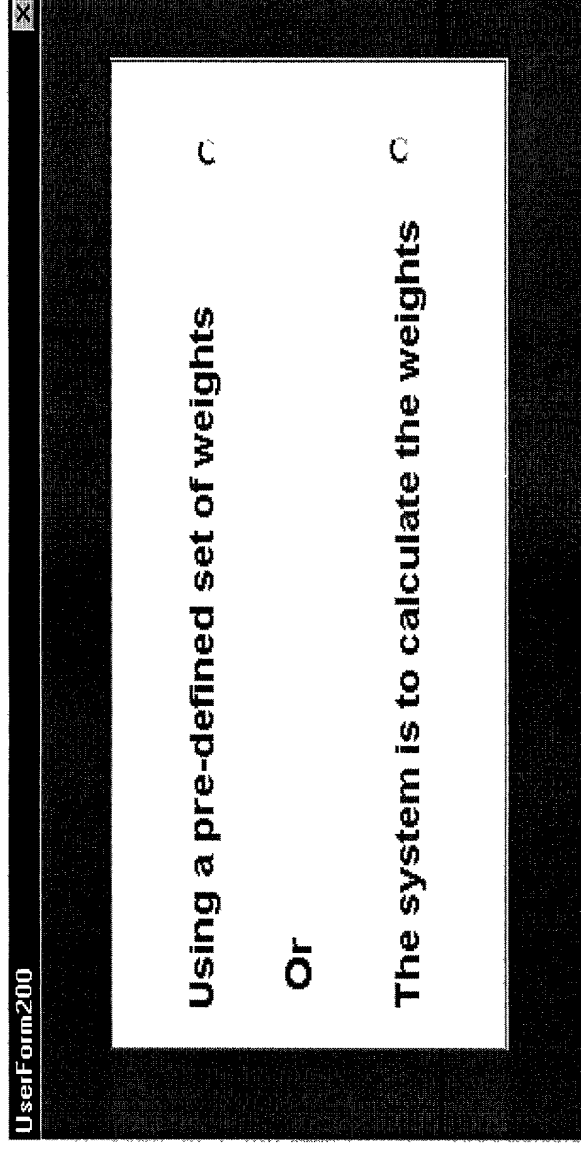
Figure 4-11: Selection of Required Mode of Weight Calculation

Figure 4-12: Feeding a Pre-Calculated Set of Weights

Figure 4-13: Retrieving a Pre-Defined Set of Weights
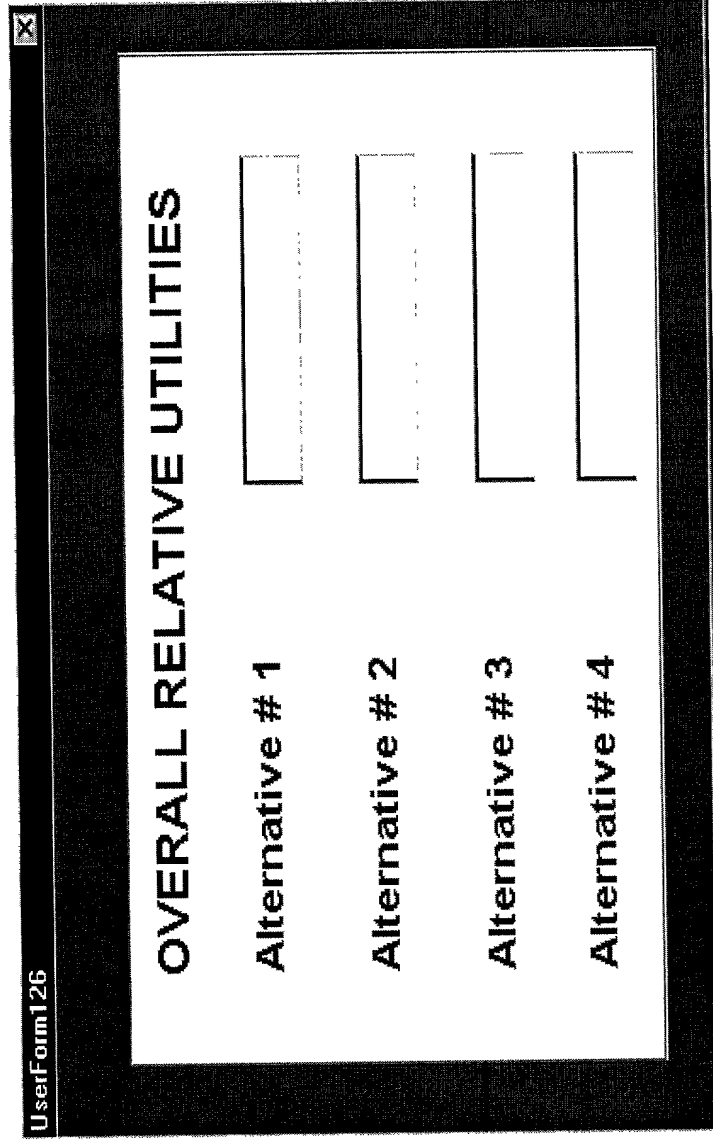
Figure 4-14: Relative Importance Screen

Figure 4-15: Weight Calculation Screen

Figure 4-16: Overall Utility Values